COMPREHENSIVE ON-STREET BICYCLE FACILITIES: AN APPROACH FOR INCORPORATING TRAFFIC SIGNAL OPERATIONAL STRATEGIES FOR BICYCLES

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COMPREHENSIVE ON-STREET BICYCLE FACILITIES: AN APPROACH FOR INCORPORATING TRAFFIC SIGNAL OPERATIONAL STRATEGIES FOR BICYCLES

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LIST OF SYMBOLS AND ABBREVIATIONS

AASHTO	American Association of State Highway and Transportation Officials
ARC	Atlanta Regional Commission
BLOS	Bicycle Level of Service
FHWA	Federal Highway Administration
HCM	Highway Capacity Manual
LOS	Level of Service
LTS	Level of Traffic Stress
MUTCD	Manual on Uniform Traffic Control Devices
NACTO	National Association of City Transportation Officials
TSOSB	Traffic Signal Operational Strategies for Bicycles
USDOT	United States Department of Transportation

SUMMARY

Bicycling is an active travel mode that addresses health risks associated with obesity and a number of environmental and social impacts imposed by decades of low cost, convenient, and efficient automobile travel. However, less than 1% of work and school trips are completed by bicycle in the United States. To both encourage and increase the mode share of bicycles, agencies are increasing investments in and adopting policies to expand and improve bicycle facilities.

Infrastructure Based Approaches are widely used to advance and minimize the cost of bicycle facility implementation. To minimize cost, Infrastructure Based Approaches dovetail the implementation of bicycle facilities with other compatible transportation projects such as planned repaving and widening to minimize costs. While meeting the objective of being cost effective, Infrastructure Based Approaches tend to produce discontinuous bicycle networks as the bicycle network is expanded over long periods of time. Discontinuous bicycle networks lack connectivity and create both real and perceived gaps in the quality of service, safety, comfort and convenience experienced by bicyclists. Casual observation of bicycle networks throughout the nation demonstrates the outcome of Infrastructure Based Approaches.

Traffic Signal Operational Strategies for Bicycles (TSOSB) include a number of traffic signal design and operational treatments to ensure safe and efficient accommodation of the bicycle mode. TSOSB are not routinely included in bicycle facilities because their impacts are not well understood and implementation guidance is limited. TSOSB have great potential to improve on-

street bicycle network continuity by improving and bridging levels of safety, comfort and convenience. A limited survey of prominent agencies with significant on-street bicycle networks revealed an awareness of; but limited implementation of Traffic Signal Operational Strategies for Bicycles (TSOSB). TSOSB have great potential to improve the perceived and actual safety, comfort and convenience of on-street bicycle facilities to reduce the level of Traffic Stress experienced by riders. Previous research has identified and grouped bicycle riders into five classes according to their level of tolerance for perceived risks to safety, comfort and convenience. The largest class, interested but concerned, could be influenced to increase their frequency of biking if perceived risks were appropriately addressed. Influencing the interested but concerned class of riders to increase the number of trips they make via the bicycle mode could significantly increase bicycle ridership.

Demand based Approaches to locate and prioritize the implementation of bicycle facilities improve upon Infrastructure Based Approaches by identifying and focusing the placement of bicycle facilities in areas that are predicted to produce bicycle trips. This research presents a simplified Demand Based Approach to identify and prioritize zones for implementation of TSOSB. An integrated land use and bicycle travel data set supports the development of a model to formulate a strength of bicycling measure. This measure can be applied to a study area to prioritize zones based on their potential to increase bicycle ridership. After priority zones are identified, the traffic signals within each zone are grouped and assessed using a tiered framework to evaluate potential gaps in safety, comfort and convenience and bicycle mode preference. The outcome of applying the simplified Demand Based Approach and tiered framework is a list of signalized intersections within priority zones. The list signalized intersections ranked according to their potential to address gaps in safety, comfort and convenience and bike mode preference.

Additional research is needed to quantify the impact of individual TSOSB. Cross-sectional studies that compare bicycle ridership across multiple jurisdictions demonstrate that comprehensive bicycle facilities improve bicycle ridership. Comprehensive bicycle facilities include a diverse set of strategies that accommodate the bicycle mode and include policies and programs to minimize the Level of Traffic Stress (LTS) experienced by riders. TSOSB are an integral component of comprehensive bicycle facilities and should be considered as a strategy to improve bicycle ridership.

1 INTRODUCTION

Acknowledgement of the environmental, social and health benefits of the bicycle mode has led to a surge in transportation policies and investment to improve the accommodation of bicycles within existing surface street networks. A documented plan describing the approach for implementation of bicycle infrastructure is required when federal funds are involved in the development of bicycle facilities. State and local agencies are increasingly documenting their philosophy, goals and approach to implementing bicycle infrastructure in Bicycle Master Plans. Many Bicycle Master Plans articulate a goal of increasing the mode share of bicycles for work and school trips as a strategy to address congestion, and improve the overall health of communities by encouraging an active mode of transportation.

Currently, about 1% of work and school trips are completed by bicycle in the United States (Alliance for Biking and Walking, 2014). The mode share of bicycles in Germany, Denmark, and the Netherlands is as high as 20%; this suggest that great potential exists to improve the mode share of bicycles in the U.S. (Purcher, Komanoff, & Schimek, 1999). On-street bike lanes are a widely implemented strategy to encourage the use of the bike mode by reserving space on the roadway for bicycles. At an aggregate level, a positive relationship exists between on-street bike lanes and bicycle ridership; however at an individual level the results are mixed (Pucher, Dill, & Handy, 2009). A number of factors contribute to bicycle ridership including climate, terrain, land use, social characteristics and the built environment. Cross-sectional studies that compare bicycle ridership across multiple jurisdictions suggests that provision of comprehensive bicycle facilities results in higher levels of bicycle ridership.

Comprehensive bicycle facilities go beyond simply reserving minimal amounts of space on the roadway in the form of on-street bicycle lanes. Comprehensive bicycle facilities employ a diverse set of strategies that prioritize the bicycle mode and include policies and programs to minimize the Level of Traffic Stress (LTS) experienced by riders (Mekuria, Furth, & Nixon, 2012) (Active Living Research, 2013). The Level of Traffic Stress (LTS) is a measure of cyclist perception of safety comfort and convenience. Geller, classified bicyclists based on four categories: Strong and Fearless, Enthused and Confident, Interested but Concerned, and No Way No How (Geller, 2006). The Interested but Concerned class is the most likely to be influenced to increase their frequency of bicycle use in response to improvements to safety, comfort and convenience. In many regions Interested but Concerned riders make up a significant percentage of the population of potential cyclist, and are the target audience of many bicycle programs. Reducing the LTS among the Interested but Concerned class of riders is integral to achieving increased bike mode share goals (Salt Lake City, 2015; Geller, 2006).

Traffic Signal Operational Strategies for Bicycles (TSOSB) may improve the safety, comfort and convenience of bicycle facilities by providing signal timings that are designed to increase the confidence of bicyclist utilizing on-street bike lanes. An observation of existing bicycle infrastructure and a review of Bicycle Master Plans among agencies with significant on-street bicycle networks, reveals that TSOSB have not been widely implemented. One potential reason for the significant gap between the implementation of on-street bicycle facilities and the supplemental implementation of TSOSB is the lack of compelling research on the impacts of the strategies. Additionally, there is also a lack of design and operations guidance describing the application of TSOSB.

Decades of providing for low cost, convenient, and efficient travel by automobile has resulted in a large network of roads that may not be conducive to the bicycle mode. When considering that on-street bike lanes are frequently implemented using Infrastructure Based Approaches; it is likely that substantial discontinuous networks of on-street bicycle lanes exist on a national scale. To increase bicycle ridership the implementation of comprehensive bicycle facilities must be strategically planned and implemented. At least two approaches for implementing bicycle facilities are evident through an observation of existing bicycle infrastructure and review of Bicycle Master Plans.

The first implementation approach, described in this research, as infrastructure based, subscribes to a philosophy that all roads should comfortably accommodate bicycles. The Infrastructure Based Approach seeks alignment with compatible infrastructure projects to incrementally build out the bicycle network while minimizing costs. The Infrastructure Based Approach recognizes the need to connect activity centers and prioritizes routes that are most suitable for and offer the least resistance to accommodating bikes. The Infrastructure Based Approach is cost effective, in that it dovetails opportunities such as repaving, widening, or reconstruction projects to provide bicycle accommodations. An undesirable byproduct of this approach is that it may not prioritize the placement of infrastructure in zones that have land uses that are most consistent with production of bicycle trips. The impact of bicycle ridership resulting from the Infrastructure

Based Approach may be difficult to measure as changes are likely to occur gradually over long periods of time.

The second approach to implementing bicycle facilities described in this research is the Demand Based Approach. The Demand Based Approach is similar to the Infrastructure Based Approach; however it adds a Latent Demand Model (LDM) to the process to evaluate trip generators and attractors to assign priority to routes with the highest connectivity between attractors and generators. The LDM considers residences as generators and businesses, parks and schools; including (colleges and universities) as attractors (Atlanta Regional Commission, 2007). The Demand Based Approach appears to be more common in Bicycle Master Plans developed in the last five years. In some respects the Demand Based Approach can be considered to be a technological advancement, which focuses the implementation of bicycle infrastructure in zones that are estimated to produce increases in bicycle ridership.

Studies quantifying the relationship between TSOSB and bicycle ridership are not included in this research. A survey was distributed to key jurisdictions with significant on-street bicycle infrastructure to assess the presence and consideration of TSOSB. The implementation of TSOSB appears to be minimal among these agencies and suggests that large networks of on-street bicycle lanes exists absent of signalized intersection treatments to accommodate bicycles. To bridge this gap, the use of a Demand Based Approach is proposed to strategically identify zones and groups of intersections that can be cost effectively retrofitted and offer the greatest potential increase in bicycle ridership by reducing the LTS of the existing on-street bicycle networks.

1.1 OBJECTIVE

Comprehensive bicycle facilities employ a diverse set of strategies aimed at prioritizing the bicycle mode to minimize the Level of Traffic Stress (LTS) experienced by riders. Traffic Signal Operational Strategies for Bicycles improve the safety; comfort and convenience of bicycle facilities by providing signal timing parameters are that are designed to meet the needs of bicyclist. Large networks of on-street bicycle lanes that lack proper traffic signal accommodations for bicycles may exists on a national scale. In the context of limited transportation funding, a strategic approach is needed to prioritize the implementation of TSOSB. The objective of this research is to develop a method to prioritize the implementation of TSOSB that offers the greatest potential to positively influence bicycle ridership.

The chapters of the thesis are organized as follows. Chapter 2 provides background information to characterize current research, implementation methods, land use relationships, and practical methods currently in use to assess the design and operation of the bike mode at signalized intersections. Chapter 3 describes Traffic Signal Operational Strategies for Bicycles in terms of their relationship to safety, comfort and convenience, and preference for the bike mode. Chapter 4 lays out a framework to develop an integrated land use bicycle travel dataset to identify critical zones and then to prioritize signalized intersections within the zone. Chapter 5 presents a case study, demonstrating the application of the model to the City of Atlanta. Chapter 6 summarizes the findings of the analysis and discusses future research needs.

2 BACKGROUND

Significant room exists to improve the use of the bicycle mode for work and school commuting. Davis, CA, and Portland, OR, are success stories; where the bicycle mode garners a mode share of 19.1% and 6.1% respectively for commute to work trips (Alliance for Biking and Walking, 2014). Bicycle ownership in the U.S., particularly among children and young adults, is significant and trends suggest that it is growing in popularity as an alternative to automobile travel among millennials (Alliance for Biking and Walking, 2014). As bicycling, walking, and transit are increasingly seen as desirable alternatives to the automobile mode; roadway design, traffic operations, and land use policies will play a significant role in the viability of these alternatives. The increasing adoption of complete streets policies and desire at both regional and local levels to increase land use density to support the use of transit, walking, and bicycling signals a shift in transportation philosophy and goals.

From a transportation planning perspective, bicycling addresses a number of issues that plague many metropolitan areas in the United States, including congestion and excess emissions, by providing an affordable travel alternative to automobiles for short trips. Section 450 of the Code of Federal Regulations describes the transportation planning process. The intent of the code is to ensure that metropolitan planning organizations comprehensively consider the needs of motorized and non-motorized users. Historically, the share of federal transportation funds for bicycle and pedestrian projects has not exceeded 2%; this level is expected to increase significantly (2014 Benchmarking).

The purpose of the metropolitan planning process is to align the needs of travelers with development of transportation infrastructure and land use. Metropolitan Planning Organizations (MPOs) throughout the United States have demonstrated a strong commitment to improve sustainability and livability of communities by advancing projects that prioritize transit, pedestrian, and bicycle travel modes. A focus on providing on-street space for bicycles at a Highway Capacity Manual (HCM) rated Level Of Service (LOS) of C or higher in many regions has resulted in substantial networks of on-street bicycle lanes. However, the lack of documentation and broad understanding among transportation professionals about the types and benefits of the traffic signal timing operational improvements for bicycles has resulted in on-street networks of bicycle lanes with virtually no accommodations for bicycles at signalized intersections. This has contributed to the creation of discontinuous bicycle networks. Regions where the implementation of on-street bicycle facilities has focused on the implementation of bike-lanes while bypassing TSOSB may require a significant investment of capital resources to address network continuity issues.

A systematic approach is needed to strategically invest constrained transportation resources to achieve the goal of increasing bicycle ridership. In the context of what are often viewed as automobile-centric goals, it is important to relate the benefits of shifting commute to work trips to the bicycle mode as a strategy to reduce congestion and minimize delays. This research provides a Demand Based Approach to identify critical zones where bicycle ridership might increase in response to comprehensive bicycle facilities, formulates a toolbox of TSOSB, and develops a process to rank the relative potential improvement to bicycle safety, comfort and convenience. The methods presented in this research are intended for application to existing on-street bicycle networks to address discontinuity in bicycle safety, comfort and convenience, which result from the absence of TSOSB.

2.1 LEVEL OF SERVICE ANALYSIS

Traffic signal operational strategies to improve the LOS for the bike mode are frequently excluded from bicycle projects, potentially due to the lack of analysis methods that adequately characterize their impacts. The Highway Capacity Manual provides a reliable level of guidance within the constraints of basic traffic signal phasing and timing and within the constraints of moderate levels of traffic demand. A review of signal timing computational methods provided by the HCM and the number of signal timing parameters in most modern controllers reveals that HCM methods account for development of only the most basic signal timing parameters. HCM methods have not kept pace with the rate new features and functions provided by most traffic signal controllers.

The Highway Capacity Manual (HCM) intersection LOS analysis for pedestrian and bicycle modes supports analysis of geometric design and signal control features. The analysis of geometric characteristics is relatively comprehensive; however, the signal timing and control elements are limited and do not include several features that are available to improve the efficiency of pedestrian and bicycle modes. HCM Chapter 17 and 18 provide computational methods for bike mode LOS at the segment and intersection level respectively. The analysis methods at both levels accommodate the analysis of traffic signal delay; however, the delay is not a factor in determining the bike mode LOS. At the segment, link, and intersection level bike mode LOS is primarily a function of geometric features and degree of saturation. HCM Equation 17-40 includes four factors in addition to the constant to determine link LOS

$$\mathrm{Ib,}_{\mathrm{link}} = 7.60 + \mathrm{Fw} + \mathrm{Fv} + \mathrm{Fs} + \mathrm{Fp}$$ (Transportation Research Board, 2010)

Where Fw is a cross-section adjustment factor, Fv is a vehicle volume adjustment factor, Fs is a speed adjustment factor and Fp is a pavement condition adjustment factor. Focusing on Fw requires an evaluation of several conditions as shown in Figure 1.

Condition	Variable When Condition Is Satisfied	Variable When Condition Is Not Satisfied
$p_{pk} = 0.0$	$W_t = W_{ol} + W_{bl} + W_{os}^*$	$W_t = W_{ol} + W_{bl}$
$v_m > 160$ veh/h or street is divided	$W_v = W_t$	$W_v = W_t (2 - 0.005\ v_m)$
$W_{bl} + W_{os}^* < 4.0$ ft	$W_e = W_v - 10\ p_{pk} \geq 0.0$	$W_e = W_v + W_{bl} + W_{os}^* - 20\ p_{pk} \geq 0.0$
v_m (1- 0.01 P_{HV}) < 200 veh/h and $P_{HV} > 50\%$	$P_{HVa} = 50\%$	$P_{HVa} = P_{HV}$
$S_R < 21$ mi/h	$S_{Ra} = 21$ mi/h	$S_{Ra} = S_R$
$v_m > 4\ N_{th}$	$v_{ma} = v_m$	$v_{ma} = 4\ N_{th}$

Notes: W_t = total width of the outside through lane, bicycle lane, and paved shoulder (ft);
W_{ol} = width of outside through lane (ft);
W_{os}^* = adjusted width of paved outside shoulder; if curb is present $W_{os}^* = W_{os} - 1.5 \geq 0.0$, otherwise $W_{os}^* = W_{os}$ (ft);
W_{os} = width of paved outside shoulder (ft);
W_{bl} = width of bicycle lane = 0.0 if bicycle lane not provided (ft);
W_v = effective total width of outside through lane, bicycle lane, and shoulder as a function of traffic volume (ft);
p_{pk} = proportion of on-street parking occupied (decimal);
v_m = midsegment demand flow rate (veh/h);
P_{HV} = percent heavy vehicles in the midsegment demand flow rate (%), and
S_R = motorized vehicle running speed (mi/h).

Figure 1 HCM Exhibit 17-21 Variables for Bicycle LOS (Transportation Research Board, 2010)

Note the computation of Wt which does not appear to recognize the impact of a marked bike lane, suggesting that they have no inherent value on the LOS of a bike facility. Roadways that carry low volumes and have adequate space in the outside lane should be properly addressed by the analysis method provided in Figure 1 above; however, as vehicle volume and speeds increase, this analysis method loses its relevance and produces uncertainty. The placement of bikes in the traffic stream or dedication of space for bicycle travel via bike lanes plays a significant role in the LOS for both the bike and automobile mode. The presence of on-street bike lanes plays a role in the level of bicycle ridership; the lack of adequate consideration of the impact of on-street bike lanes at the intersection level of analysis is significant as it is within the decision tree of whether or not bike lanes should be included in the facility design (Transportation Research Board, 2010). The AASHTO guide for the development of bicycle facilities raises awareness of the inconsistencies in LOS analysis in the HCM but does not resolve the conflict with alternative methods. Additional support for the value of bike lanes can be found in the Highway Safety Manual which identifies the use of wide curb lanes and dedicated bicycle lanes as a countermeasure to reduce the risks of vehicle bicycle crashes (AASHTO, 2010; FHWA, 2006). Signalized intersections can present significant barriers to bicycling; provision of on-street bike lanes is consistent with the goal of increased bicycle ridership. Operational objectives for bicycles should be formulated to guide the application of TSOSB, a number of which are widely available and can be implemented for relatively low cost. TSOSB may be directed at improving bicycle safety, comfort and convenience, and maximally a preference for the bicycle mode.

2.2 BICYCLE FACILITIES AND BICYCEL RIDER CHARACTERISTICS

A significant amount of recent research has shifted classification of bicycle facilities from traditional Level of Service (LOS) ratings to a more user perception oriented, Level of Traffic Stress (LTS). Level of Traffic stress rates bicycle rider tolerance for a number of criteria including level of traffic, space accommodation and speed of adjacent traffic. (Mekuria, Furth, & Nixon, 2012) (Transportation Research Board, 2010). The primary motivation for the development of LTS was the lack of adequate consideration of bicyclist behavior in documents such as the HMC. LTS does not consider the effects of signalized intersection operation, but rather focuses on the speed and volume of traffic in lanes adjacent to bike lanes, parking, separation, and other factors that would make a route “traffic-intolerant.” (Mekuria, Furth, & Nixon, 2012). Previous to the LTS work a widely used scheme for classifying riders that remains ubiquitous is included below in Table 1.

Table 1 Bicycle Rider Classification, (Geller, 2006)

Rider Classification	Classification Description
No Way, No How	Typically low skilled and have an extremely negative perception of the safety of on-street bike lanes and under no circumstances would consider riding in on-street bicycle lanes.
Interested but Concerned	Riders in this class possess a low level of skill but demonstrate a willingness to gain the proper education and experience to increase their confidence in utilizing on-street bicycle lanes. Attracting this class of riders to regularly utilize the bicycle network is the objective of enhancing existing facilities to remove barriers to perceived safety, comfort and convenience.
Confident & Enthused	Riders in this class have the skills and education to feel comfortable riding in on-street bike lanes and interacting with automobiles to cautiously utilize the bicycle network for utilitarian and recreational purposes. Retaining and expanding the use of the bicycle network for this class of riders would be an objective of incorporating TSOSB into existing on-street bicycle networks.
Strong & Fearless	This class of rider is comfortable riding a bicycle under any condition and feels a sense of ownership over the road and demands the same respect as automobiles as the rider under all ranges of traffic conditions. The enhancement of existing on-street bicycle infrastructure has little potential to change the ridership commitment of this class of riders.

Bicycle Master Plans generally include enhancement and education strategies as an approach to achieve higher levels of bicycle ridership. TSOSB are frequently deferred as the bicycle networks are constructed due to a lack of understanding of TSOSB's operational objectives and potential benefit. Wide and complex signalized intersections are frequently viewed as barriers to bicyclists in the interested-but-concerned skill level; the provision of TSOSB may address concerns about signalized intersections (Atlanta Regional Commission, 2007).

The sensitivity of the Level of Traffic Stress (LTS) rating system to bicyclist perceived concerns adds a dimension to facility analysis that is not comprehensively considered in HCM and AASHTO rating systems for bicycle facilities. The HCM, discussed in section 2.4, is primarily concerned with the provision of space and doesn't demonstrate sensitivity to how space is allocated to bicycles with lane markings. For example, a bicycle rider would certainly experience a different level of stress when traveling in a wide unmarked shoulder lane versus a marked buffered bicycle lane. The HCM might treat the two facilities very similarly but riders would experience much different levels of stress. The LTS process is systematic and has been used to produce maps that demonstrate network connectivity. The LTS ratings evaluate a number of criteria, including: segment configuration, width, operating space, speed, bike lane blockage, mixed traffic, and intersection approach treatments (Mekuria, Furth, & Nixon, 2012). Stress level 1 is consistent with a level of stress suitable for children; stress level 2 represents a stress level suitable for adults; while 3 and 4 represent stress levels greater than level 2 that would not be tolerable by most adults. (Mekuria, Furth, & Nixon, 2012)

2.3 BICYCLE MASTER PLANS

Increasing bicycle ridership is an explicit goal stated in many regional and local Bicycle Master Plans that lay out the vision, goals, objectives, and design strategies to increase bicycling mode share (Alliance for Biking and Walking, 2014). At the core of bicycle infrastructure is on-street bicycle lanes; an acknowledgement of the difference in operating characteristics and the vulnerability of bicycles, to separate bikes from vehicles by reserving space to improve safety, comfort, and convenience. Several regions have and continue to contribute significantly larger portions of transportation funding to bicycle and pedestrian projects and it is these regions on which this review will focus as they are most likely to possess advanced, proven, and innovative techniques for implementing bicycle infrastructure as well as signalized intersection operational strategies.

Bicycle Master Plans have guided the implementation of bicycle infrastructure over the last decade, to produce networks of bikeways that support utilitarian and recreational use. A number of prominent agencies, implementing significant on-street bike facilities are included in Table 2 below. Table 2 supports comparison of bike facility implementation approach, population density, bike facility density and percentage of commuters that bike to work. The bicycle facility implementation approach is classified as Infrastructure Based Approach (IBA), Demand Based Approach (DBA) or some combination of the two. Each Bicycle Master Plan as reviewed to determine the implementation approach.

Table 2 Summary of Bicycle Implementation Approach

Location	Population Density[1] (population per acre)	% of Commuters Bike to Work[2]	Bike Facilities Density[3] (miles per sq. mi)	Miles of On Street Bike Lanes[4]	Bike Facility Implementation Approach	BMP Date
Davis, CA	7,204	19.1%	16.4	109	IBA	2012
San Francisco, CA	17,179	3.3%	7.8	120	IBA	2009
Boulder, CO	3,947	10.2%	7.5	73	IBA	2012
Eugene, OR	3,643	8.5%	5.2	150	IBA	2012
Fort Collins, CO	2,653	6.3%	4.2	171	DBA	2014
Mesa, AZ	3,218	1.0%	4.2	360	DBA.	2013
Albuquerque, NM	2,908	1.4%	4.1	400	IBA	2000
Minneapolis, MN	7,088	3.6%	3.9	116	IBA	2011
Seattle, WA	7,251	3.4%	3.9	129	IBA	2007
Boston, MA	12,793	1.7%	3.8	80	IBA	2013
Washington, DC	9,856	2.9%	3.8	79	IBA	2005
Madison, WI	3,037	5.2%	3.6	112	IBA	2000
Portland, OR	4,375	6.1%	3	320	DBA/IBA	2010
San Diego, CA	4,020	0.9%	2.6	620	DBA	2013
Salt Lake City , UT	1,678	2.5%	2.3	190	IBA	2015
Atlanta, GA	3,154	1.1%	0.7	62	DBA/IBA	2007
New Orleans, LA	2,029	2.3%	0.3	36	IBA	2005

Infrastructure Based Approach (IBA), Demand Based Approach (DBA)

1 (USDOT, 2009) (US Census Bureau, 2015), 2-4(Alliance for Biking and Walking, 2014),

2.4 LAND USE AND BICYCLE RIDERSHIP

The operating hypothesis of land use models is that demographic, socio-economic, and other variables that depict the built environment can be used to demonstrate relationships to bicycle travel. The wide application of land use models by Metropolitan Planning Organizations to guide the analysis of transportation investment decisions for the automobile and transit modes suggests a high degree of confidence in their ability to accurately predict travel choices. Land use models developed for the automobile and transit mode are fueled by rich sources of data that support the development of substantive relationships. The mode share of bicycles for work based trips according to surveys at the national, regional and local levels is typically less than 1% resulting in reliability issues associated with models that estimate bicycle ridership.

Several recent efforts have produced models that have positively correlated land use variables such as employment, income level, and auto ownership with bicycle ridership. Cui et al., (2015) developed a land use model to predict future bicycle ridership for the State of Maryland using data from the U.S. Census American Community Survey, and state and local Metropolitan Planning Organizations (MPOs). The Maryland study utilized a Spatial Lag Model (SLM) and forward selection process to develop several models correlating daily bicycle ridership with densities of population, zero-worker households, and school enrollment (Cui, Sabyasachee, & Welch, 2015). Within urban areas, the model was sensitive to population and school enrollment producing higher levels of bicycle ridership as these variables increased.

Bicycle ridership has a number of influences, including climate, terrain, crime, and the quality of pavement that must be considered and if possible controlled in the development of land use models. Salon & Handy, (2014) developed land use models to prioritize bicycle infrastructure investments by estimating the intensity of biking at the census tract level. The basic methodology involved first joining neighborhood type (rural, suburban, urban, and central city) to census tract. Second, the miles biked and walked for each survey respondent was calculated and assigned to a category based on age, gender, and neighborhood type. The last step in the process was to calculate average miles biked and walked by category and assign them to population totals. The result of the analysis was that pedestrian and bicycle intensity of infrastructure increases with the population density and that crash rates are lowest in the most urban areas and highest in rural areas. In other words, when the percentage of commuters who walk or bicycle to work increases, the corresponding fatality rates decrease (Alliance for Biking and Walking, 2014). As more comprehensive bicycle facilities are implemented, bicycle ridership increases. The Salon and Handy study in California, similar to the findings in the Maryland study, demonstrated a strong relationship between population density and intensity of bike ridership.

2.5 SUPPORT FOR TSOSB

Quantitative study of the impact of TSOSB on, safety, comfort, convenience, and bicycle preference at signalized intersections is lacking. A growing number of policies, agency practices, and guidance are advancing TSOSB in the absence of quantitative evaluation of the impacts of these strategies. A questionnaire, available in appendix A, was distributed to 14 agencies, to identify practices and guidance that is currently used by agencies to make decisions about which strategies and under what conditions they consider TSOSBs. The density of on-street bicycle lanes and bicycle ridership levels are shown in Figure 2; the agencies listed in the chart, with the exception of Atlanta, are shown for comparative case study and represent some of the highest densities of on-street bike lanes in the United States. Several of these agencies as a matter of policy have opted to include bicycle minimum green, clearance time, and detection on all bicycle routes. Traffic signal enhancements for bicycles become more prevalent as the density of these networks increase.

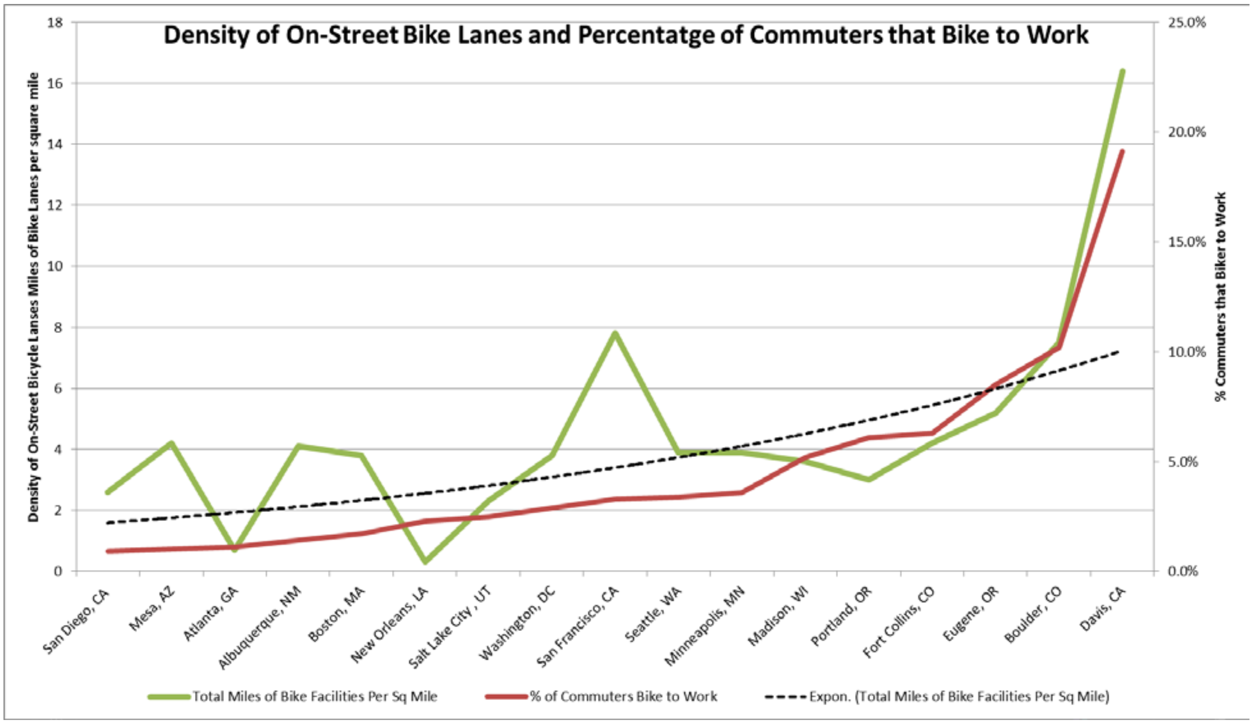

Figure 2 Chart - Density of On-Street Bicycle Facilities & % Commuters Biking to Work (Alliance for Biking and Walking, 2014)

Portland, OR; Davis, CA; and Madison, WI; have each articulated very clearly in planning documents a preference for a growing share of the bicycle mode for all trip purposes (Portland Bureau of Transportation , 2010) (City of Davis , 2009) (Madison Urban Area and Dane County, 2000). The motivation & decision criteria for installation of TSOSB was explored in online surveys distributed to 21 agencies (2 in Canada) believed to have bicycle specific traffic signals installed within their jurisdiction. The survey included a narrative question regarding the agencies motivation for installing a bicycle traffic signal and typical responses included prevention of cyclist noncompliance, contraflow bicycle movement and safety concerns. The survey is discussed in chapter 3.2 and included in the appendices.

2.6 EXISTING TRAFFIC SIGNAL TIMING AND OPERATIONAL PARAMETERS FOR VEHICLES AND BICYCLES

The purpose of this section is to examine existing vehicle and bicycle traffic signal timing operational parameters and features. Bicycle riders are extremely vulnerable to injury and the potential to sustain life threating injuries in the event of a collision with an automobile (AASHTO, 2012). The operating characteristics of bicycles are substantially different than that of automobiles. The ability of bicycles to accelerate, and decelerate and the speeds they are able to attain and sustain are contingent on a number of variables such as the fitness and physical condition of the bicycle operator as well as the type and quality of bicycle itself. The behavior of bicyclist at signalized intersections is an area that is ripe for research to gain a better understanding of their needs, operating characteristics and preferences.

The AASHTO Policy on the geometric design of highways and streets clearly states that the needs of bicyclists should be adequately considered in all phases of transportation planning, design, and operation (AASHTO, 2012). Based on what is currently understood about bicycles a limited number traffic signal timing parameters have been developed to provide for some degree of safety and to maintain intersection efficiency when bicycles are present. There are also a number of vehicle specific features and parameters that while not designed specifically to address bicycles may have the ability to improve intersection safety or efficiency when adapted to accommodate bicycles.

Traffic Signal Controllers are specialized field computers that manage the right-of-way at signalized intersections. These devices manage the duration and sequence of the traffic signal indications for vehicles, bicycles and pedestrians at signalized intersections. In the absence of bicycle specific traffic signal indications, bicycles are generally required to comply with vehicle indications. Relative to vehicles, bicycles present a higher degree of variability with respect to consistency in operational characteristics (Taylor & Mahmassani, 2007). One of the complexities associated with serving bicycles at signalized intersections is that depending on the experience and preference of the rider they might behave like a vehicles or pedestrian. It is also entirely possible that the behavior of bicycles at signalized intersections is a function of the accommodations provided for them; again, this is an area where additional research is needed.

2.6.1 VEHICLE AND BICYCLE MINIMUM GREEN

Minimum (vehicle) green is a fixed signal timing interval that is set to meet the expectancy of drivers to recognize a green indication and proceed through the intersection (FHWA, 2008). In a pre-timed or fixed mode of operation (e.g. no vehicle detection present) minimum green is typically set to provide the total amount of green time required for a vehicle phase. In an actuated mode of operation the minimum green time is set to meet driver expectancy and the storage of vehicles between the stop line and detection devices. The time required for bicycles to start from a standing position and to enter the intersection should minimally be provided by the vehicle setting for minimum green when no bicycle minimum green setting is available. The computation of standing bicycle crossing time should be used to design the setting for Bicycle Minimum Green (BMG) time when the feature is available in the traffic signal control device

(AASHTO, 2012). When a BMG feature is not available with a compatible mechanism to call the BMG setting into use when a bicycle call is placed, the vehicle minimum green time for the appropriate phase must accommodate the bicycle crossing time. When a green indication for a phase begins, bicyclists require enough time to react to the green indication and cross the intersection from a stopped position. The AASHTO formula to estimate the minimum bicycle crossing time at the beginning of green is computed as follows:

$$\mathrm{BMG} = \mathrm{BCT}_{standing} - \mathrm{Y} - \mathrm{R}_{Clear} = \mathrm{PRT} + \frac{\mathrm{V}}{2\mathrm{a}} + \frac{(\mathrm{W}+\mathrm{L})}{\mathrm{V}} - \mathrm{Y} - \mathrm{R}_{Clear}$$

(AASHTO, 2012)

BMG = bicycle minimum green interval (s),
PRT = perception and reaction time = 1s,
Y = length of vehicle yellow interval (s),
R_{Clear} = length of vehicle red interval (s),
W = Intersection width (ft.),
Note: MUTCD-CA W = Limit Line to far side of last conflicting lane
L = typical bicycle length = 6ft,
a = bicycle acceleration = 1.5 ft. /s^2, and
V = bicycle crossing speed = 14.7 ft. /s or 10mph.
(Source AASHTO Guide for the Development of Bicycle Facilities, 2012)

The FHWA Signal Timing Manual provides typical settings for minimum green time for specific types of facilities as shown in Table 4 below A column is included in the table to demonstrate that typical minimum green times are not sufficient to accommodate bicycles and must be increased to guarantee that adequate time is available for them to start up and cross the intersection prior to the onset of yellow. The case study of the City of Atlanta included later in the report provides the computation of minimum green for minor collectors, minor arterials and major arterials

Table 3 Vehicle Minimum Green Time based on Facility Type (FHWA, 2008)

Facility Type	Vehicle Minimum Green Time	Bicycle Minimum Green Time
Major Arterial (speed limit exceeds 40 mph)	10 to 15	8 - 12
Major Arterial (speed limit is 40 mph or less)	7 to 15	8 - 12
Minor Arterial	4 to 10	7 - 10
Through Collector, Local, Driveway	2 to 10	5 - 8
Left Turn Any	2 to 5	5 -8

The California MUTCD provides guidance on the design of minimum bicycle timing that is based on the width of the intersection from limit line to the far side of the last conflicting lane. This provides clarity about how the width of the intersection should be measured as the AASHTO guide leaves some flexibility about the measurement of the width which could significantly impact the timing of the minimum green as shown in Figure 3 below.

Table 4D-109 (CA). Signal Operations - Minimum Bicycle Timing

$G_{min} + Y + R_{clear} \geq 6$ sec + (w+6 ft)/14.7 ft/sec, where

G_{min} = Length of minimum green interval (sec)

Y = Length of yellow interval (sec)

R_{clear} = Length of red clearance interval (sec)

W = distance from limit line to far side of last conflicting lane (ft)

Distance from limit line to far side of last conflicting lane	Minimum phase length (minimum green plus yellow plus red clearance)
Feet	Seconds
40	9.1
50	9.8
60	10.5
70	11.2
80	11.9
90	12.5
100	13.2
110	13.9
120	14.6
130	15.3
140	15.9
150	16.6
160	17.3
170	18.0
180	18.7

Figure 3 CA MUTCD Minimum Bicycle Timing (Caltrans, 2014)

Bicycle minimum green has implications to bicycle safety due to the difference in dynamics between bicycles and automobiles. Bicyclists who experience inadequate minimum green time are likely to observe vehicles beginning to enter their path of travel before completing the intersection crossing. The level of discomfort experienced by bicyclists is related to the type and experience of the cyclist. Of the four classes or riders described in Table 1,(No Way, No How; Interested but Concerned; Confident & Enthused; Strong & Fearless) inadequate minimum green time could be a significant deterrent to bicycle ridership among the interested but concerned class of bicyclists and a safety issue with all riders.

2.6.2 VHEICLE AND BICYCLE CLEARANCE

The yellow interval, which warns drivers of an impending change of right way, and the red clearance interval, is provided to allow a vehicle that just enters the intersection at the end of yellow to traverse the intersection before conflicting movements are released (FHWA, 2008). The use of the ITE kinematic equation to develop Yellow and All-Red Clearance intervals is common practice (FHWA, 2008). The ITE Kinematic equation is shown below. The first two terms are used to compute the yellow interval, with the posted speed limit plus five miles per hour typically used as the approach speed as a substitute for the 85th percentile speed. The third term provides the All-Red clearance time.

$$CP = t + \frac{1.47\, v}{2(a+32.2g)} + \frac{W+L_v}{1.47v}$$ (FHWA, 2008)

Where

CP = change period (yellow change plus red clearance intervals), s,

t = perception-reaction time to the onset of a yellow indication, s,

v = approach speed, mph ft. /s,

a = deceleration rate in response to the onset of a yellow indication ft. /s^2,

g = grade, with uphill positive and downhill negative (percent grade / 100), ft. /ft.

W = width of intersection, ft., and

Lv = length of vehicle (ft.).

For bicycles to safely cross the width of an intersection at the end of a green interval the vehicle change period must accommodate the crossing time of bicycles to traverse the intersection before conflicting traffic movements receive a green indication. The AASHTO bicycle guide provides a computation for a rolling bicycle to cross an intersection as follows:

$BCT_{rolling} = \frac{BD + W + L}{V} = \frac{PRT * V + \frac{V^2}{2a} + W + L}{V}$ (AASHTO, 2012)

$$BD = PRT * V + \frac{V^2}{2a}$$

Where

BCT = bicycle crossing time (s),

BD = braking distance (ft.),

W = intersection width (ft.), and

V = 10mph (14.7ft/s)

a = bicycle deceleration rate for wet pavement = $5 ft/s^2$

The AASTHO bicycle guide does not recommend the adjustment of the yellow interval. The difference in speed and deceleration rates for automobiles and bicycles produces larger clearance intervals for bicycles and significantly impacts the capacity of the intersection, as all-red clearance time is not available to productively serve movements of any mode. The MUTCD limits the duration of the red-clearance interval to a maximum of six seconds; therefore, in the event of clearance time requirements in excess of six seconds other alternative strategies must be pursued, such as adaptive green which is capable of extending the green time when a bicycle is detected on the approach just before the onset of yellow and requires additional green extension to cross the intersection. .Figure 5, below provides a summary of the five survey responses on the use of Bicycle Clearance Time.

2.6.3 VEHICLE AND BICYCLE DETECTION

In a fixed time operation the traffic signal controller steps predictably through a fixed sequence and duration of phases each cycle. To reduce delay an actuated mode of operation incorporates the capability of aligning green time to traffic demand by serving phases only in response to request for service. To receive green time, a call for service must be placed via a detection device. The purpose of bicycle detection is to provide a call for service to the traffic signal controller responsible for managing the right-of-way at a signalized intersection. Detection is only relevant for actuated phases; phases operating in a fixed time mode are recalled and served at least once every cycle, in a repeating sequence. In an actuated mode, intersections must be equipped with detectors or push buttons that are placed and marked specifically to receive bicycle calls. In the absence of bicycle detection, bicycles must find a means of placing calls to vehicle or pedestrian phases to be serviced.

Agency traffic design manuals may include standard configurations and requirements for bicycle detection on designated bicycle routes; the detection of bicycles can be achieved with a number of detection technologies (Mesa, AZ , 2014). The NACTO Urban Bikeway Design Guide identifies detector accuracy and clear guidance to bicyclists on how to use detection devices as the two most important principles of bicycle detection. Inductive loops are the most widely deployed device to detect automobiles. The sensitivity of loop detectors can be adjusted to detect bicycles and the addition of pavement markings to direct bikes to the loops is important to facilitating their use. Recent behavior studies demonstrate that bicyclists have low recognition of how to be detected at signalized intersections and generally assume their presence is not acknowledged at signalized intersections resulting in a significant level of non-compliance with intersection displays (Boudart, Liu, Koonce, & Okimoto, 2015). The Manual on Uniform Traffic Control Devices (MUCTD) recently introduced the 9C-7 pavement marking and R10-22 sign to provide cyclists with guidance on the location of and process for being detected at signalized intersections, see Figure 6 below. The California MUTCD Section 4D.105 (CA) takes a technology neutral position on bicycle detection and requires all new or modifications to existing limit line detection to provide the capability of detecting bicycles. California is currently the only state that has mandated bicycle detection. The requirement was included in the 2014 CA-MUTCD released in November of 2014.

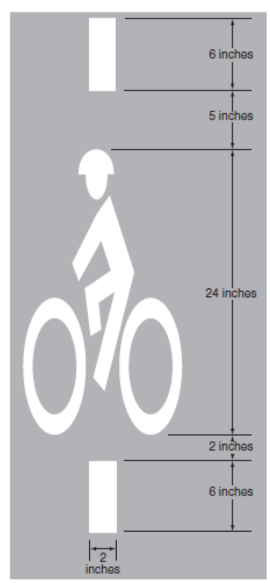

Figure 4 Bicycle Detector Pavement Marking (MUTCD 9C-7) & Sign (MUTCD R10-22)

Source: Manual on Uniform Traffic Control Devices for Streets and Highways 2009 Edition

Technology selection for bicycle detection must respond to the needs of bicyclists to be accurately detected and to provide awareness of the detection process. The four dominant technologies for vehicle detection are inductive loops (discussed above), video image detection and microwave sensors (USDOT, 2013). While each of these devices is capable of detecting bicycles, each has limitations in terms of accuracy and precision that must be considered. Studies have shown that inductive loops are able to detect even composite bicycles if the wheels are equipped with a circumferential band for the purpose of braking (Krogmeier, 2008). When presented with multiple detection options such as an advanced detector, stop bar detector, and push button, the bicyclists appear to acknowledge the push button as the most reliable form of detection (Boudart, Liu, Koonce, & Okimoto, 2015). The addition of feedback devices such as a blue LED incorporated into placards to indicate bicycle detector status, Figure 7 below, were tested in Portland, OR. Early results of evaluations of the feedback device support its ability to increase bicyclist recognition of detection.

Figure 5 - Bicycle Detection Feedback Device

Photo Source: (Boudart, Liu, Koonce, & Okimoto, 2015)

Bicycle detection is typically located to detect bicycles at the stop bar and supplemented with a pushbutton. Detection placed in advance of an intersection allows approaching bicycles to place calls for service to reduce waiting times and also potentially to actuate extension timers, discussed in more detail below.

The need for bicycle detection at signalized intersections is contingent on the mode of operation and geometric configuration of the intersection. To assess the need for bicycle detection, three typical scenarios are offered. The scenario that most closely fits the mode of operation and geometric configuration under consideration should be applied to assess the need for bicycle detection. The lack of adequate detection for bicycles increases the risk of non-compliance with traffic signal indications and increases crash risks.

2.6.3.1 SCENARIO 1- FIXED TIME OPERATION

Signalized intersections that operate in a fixed-time mode recall phases sequentially every cycle and do not require the use of vehicle, pedestrian, or bicycle detection. Fixed-time operation is appropriate for Central Business Districts and urban areas where the presence of pedestrian and regularly spaced intersections supports the use of short cycle lengths and minimizes the number of phases (NACTO , 2013).

2.6.3.2 SCENARIO 2 – ACTUATED MODE OF OPERATION WITHOUT ON-STREET BICYCLE LANE

The use of actuated control is most common on major arterials and suburban and rural roads where the operations objective is to provide smooth flow along the arterial by utilizing coordinated signal timing and minimizing service to side streets and left-turns through the use of actuation (FHWA, 2008). When a Sharrow or no on-street bicycle facilities are provided, it may be not clear to bicycles where they should position themselves to be detected. Detectors should be sensitive enough to detect bicycles and their position, confirmed with the use of pavement markings. As the bicycle mode becomes more prominent as a primary mode of transportation many states may follow the lead of California, eventually requiring the detection of bicycles at traffic actuated locations (CVC 21450.5, 2007). Ideally, bicycle detectors and pavement markings should be provided in at least the rightmost lane and left turn lanes when the left-turn phase is actuated. The use of a bicycle push-button in addition to or in place of bicycle detection is also recommended.

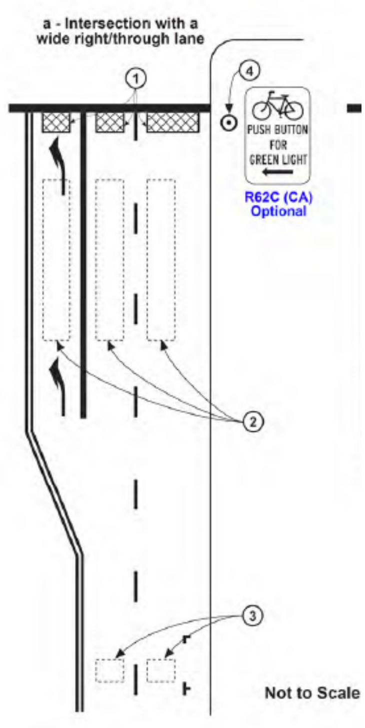

Figure 6 Typical Layout of Intersection Approach without On-Street Bicycle Lane (Caltrans, 2014)

2.6.3.3 SCENARIO 3 - ACTUATED MODE OF OPERATION WITH ON-STREET BICYCLE FACILITY

To maintain the continuity of the bicycle network and especially in the presence of on-street bicycle lanes, the use of bicycle detection is essential and should include pavement markings and the addition of signage and pushbuttons as shown in Figure 8 above. Guidance on the benefits of bicycle detection, including placement, use, technology and methods for identification of the detection position with lane markings and signs is readily available (Thompson, Monsere, Figliozzi, Koonce, & Obery, 2013). Ideally, the use of detector technology that is capable of detecting bicycles separately from vehicles would allow special features such as bicycle minimum green, bicycle extension, and bicycle clearance to be served separately from vehicle phase intervals to maintain the efficiency of the intersection while maximizing the comfort, convenience, and safety of bicycles (FHWA, 2006). Bicycle detection should be placed both at the stop bar and in advance of the intersection to minimize control delay for bicycles.

2.6.3.4 BICYCLE DETECTION RELATIONSHIP TO INTERSECTION SAFETY

The National Highway Transportation Safety Administration (NHTSA), National Center for Statistics and Analysis, reports annual fatality statistics for pedestrians and bicyclist in addition to other modes. The 2012 NHTSA, Traffic Safety Fact Sheet for Bicyclist indicates that 69% of all bicycle fatalities occur in urban areas versus 21% in rural and 30% of all cyclist fatalities occur at intersections. While the report does not distinguish between signalized and non-signalized intersections, a recent bicyclist behavior study in Portland, OR recorded a non-compliance rate of 13.8% for bicyclist running red lights. Bicyclists benefit substantially from detection and the addition of feedback devices to confirm detection has the potential to enhance compliance and improve safety

2.6.4 SHORT CYCLE LENGTHS

Users of signalized intersections have a low tolerance for delay when it is not equitably distributed and the source of the delay is not easy to perceive and consistent with the expectation of intersection users (FHWA, 2009). In 2010, NHTSA reported that 30% of all bicyclist fatalities occurred at intersections. It is worthwhile to note that a comparison of signalized versus non signalized intersections was not provided for this statistic. Observations of bicyclists at signalized intersections have shown a high tolerance when expected delay is 10 seconds or less.

As delay increases, bicyclists become less tolerant and bicyclists become more likely to violate the signal as delay exceeds 30 seconds (Transportation Research Board, 2010) (Pucher, Dill, & Handy, 2009). Bicycle delay at signalized intersections is sensitive to the ratio of green time and overall cycle length. A brief analysis confirms that, as cycle lengths increase beyond 90 seconds and green time decreases to less than 28% of the cycle length, bicycle delay increases beyond levels that are tolerable to bicyclists (Transportation Research Board, 2010). The NACTO Urban Street Design Guide recommends that cycle lengths not exceed 120 seconds. Long cycle lengths can result in long wait times that could be perceived as barriers and significantly detract from the desire to bike or walk.

2.6.5 PASSAGE TIME

Passage time, also referred to as extension time, is relevant in the context of the actuated mode of operation. The duration of a vehicle phase is determined by three distinct intervals; green interval, yellow change, and red clearance interval (FHWA, 2008). The duration of the green interval is dictated by three timers: the first is the minimum green timer (discussed in a previous section); the second is the extension timer and finally, the maximum green timer. When the green indication is initiated, the minimum green time begins to count down as it provides time for vehicles to start up and begin to enter the intersection. When the minimum green timer reaches zero, the green interval will terminate without additional actuations to hold the phase. The extension timer is the logic mechanism that holds the phase when it receives requests for continued service from detectors. Similar to the minimum green timer, the passage timer counts down from its setting usually in the range of 1.5 to 5 seconds and terminate the phase when it reaches zero. The passage timer is reset each time it receives additional actuations.

A bicycle detector may be configured to provide additional green time for bicycles with each actuation and is usually set to allow bicycles to enter the intersection such that additional red-clearance is not required beyond that provided for vehicles (AASHTO, 2012). Bicycle passage time may serve several objectives. In the context of intersection clearance it satisfies a safety function, in the context of extending green time it helps to avoid phase termination and additional delay to the cyclist. Preference for the bicycle mode would be achieved by providing passage time for bicycles.

2.6.6 ACUTATED COORDINATED OPERATION

In a coordinated mode of operation, the coordinated phase is not actuated, but recalled and served every cycle receiving its full allocation of green time as well as the unused green time from other actuated phases. This operation maximizes the green time provided to the coordinated phases regardless of whether or not demand is present. When demand for the coordinated phases is much lower than the excess capacity resulting from additional green time; bicycles and vehicles waiting for other phases will experience excessive delay. Standard coordinated operation has great potential to produce excess delay for non-coordinated phases when demand is below peak period levels.

The probability of bicycles violating traffic signal indications increases as delay exceeds 30 seconds. (Transportation Research Board, 2010). Coordinated operation under low demand conditions has a high likelihood of creating an operation that does not appear to be equitable to users waiting for non-coordinated phases. Actuated coordinated operation addresses this issue by allowing a portion of the coordinated phase to be designated as an actuated interval allowing it to terminate early. This allows unused green time to be allocated to other phases, reducing their delay. The objective of actuated coordinated operation is consistent with bicycle objectives to improve comfort and convenience. Excessive delays may result in low compliance with traffic signal indications; therefore, actuated coordinated operation could also be considered as a safety treatment.

2.6.7 TURNING MOVEMENT TREATEMENTS

Crash data frequently identifies motorists turning left and right in front of a straight moving cyclist as a prevalent crash type. Measures to restrict the movement of vehicles across the path of bicycles to address the potential for left and right hook crashes with on-street bike lanes has been implemented in a number of jurisdictions (Steinman & Hines, 2004). To reduce the potential for left-turn vehicle/bicycle conflicts the use of protected/prohibited left-turn phasing provides the greatest protection for bicycles. Figure 13 below provides an example of a protected only left turn phase to restrict the movement of vehicles during bicycle movements, this configuration and associated signal timing reduces the potential of bicycle conflicts with left turning vehicles.

Figure 7 Example of Restrictive Left-Turn Vehicle Movement

(Source: Flying Pigeon Bicycle Shop, http://flyingpigeon-la.com/wp-content/uploads/2011/04/LBC_cycletrack_signals_01.jpg)

In the case of protected/permissive or permissive left-turn phasing the use of leading bicycle intervals could improve safety by allowing bicycles to proceed in advance of vehicles. Right-turns- on red are a frequent source of bicycle/vehicle crashes that can be mitigated by restricting right-turn-on-red or the use of protected/prohibited right turn phasing to restrict right turns to green intervals when right-turns are given right-of-way.

2.6.8 BICYCLE GREEN WAVES

The purpose of the coordinated mode of traffic signal operation is to minimize the number of stops that vehicles encounter when traveling through closely spaced intersections by establishing a common time reference to synchronize green indications to the speed of vehicles. Bicycle green waves apply the same coordination techniques for automobiles by utilizing bicycle travel speeds to synchronize green indications. The objective of bicycle green waves is to improve the comfort and convenience of the bicycle mode by minimizing stops at red lights (City of Salt Lake City, 2015). Bicycle green waves may also demonstrate a preference for the bicycle mode when the automobile travel speeds are not a multiple of bicycle travel speed resulting in the potential for increased stops at red lights for automobiles.

2.6.9 EXCLUSIVE BICYCLE PHASES

An exclusive bicycle phase restricts the movement of all automobile, pedestrian and bicycle movements at intersections that are not designated for service during the intervals of the exclusive phase. An exclusive bicycle phase may utilize bicycle specific traffic signals to control cyclist movements and are not typically viewable by other motorists or pedestrians. (Thompson, Monsere, Figliozzi, Koonce, & Obery, 2013). Exclusive bicycle phases are generally used as a safety countermeasure (Pucher, Dill, & Handy, 2009) in locations where the complexity of the bicycle movement imposes safety risks that are most effectively mitigated by constraining the right of way exclusively to bicycles during the phase. A review of case study data suggests that exclusive bicycle phases are used frequently when the geometry of the intersection or intended path of the bicycle is non-standard (DDOT, 2012).

The primary drawback of an exclusive bicycle phase is that a significant level of vehicle and bicycle delay is usually associated with its design. Exclusive phases by definition are not compatible with other phases and therefore the movement(s) served by the exclusive phase is restricted during all other phases. The use of an exclusive phase in tandem with a detection feedback light to confirm to bicyclists that a call for the phase had been placed resulted in a 13.8% violation rate (Boudart, Liu, Koonce, & Okimoto, 2015).

2.6.10 BICYLE SPECIFIC TRAFFIC SIGNALS

Bicycle specific traffic signals provide phase indications that are intended to communicate right-of-way information exclusively to bicycles. The MUTCD provides minimal guidance on the style and placement of bicycle specific traffic signals and some variation in the style and placement of bicycle specific traffic signals can be found throughout the United Sates. The MUTCD-CA provides an example of a bicycle signal face as shown in Figure 16 below.

Bicycle specific traffic signals are frequently supplemented with signs to communicate that their use is to be associated with bicycles. A state of the practice review, conducted by the City of Portland, OR describes the primary use of bicycle specific traffic signals is in combination with exclusive bicycle phases and pavement markings to delineate a unique path for the bicycle (Thompson, Monsere, Figliozzi, Koonce, & Obery, 2013). The most prevalent use of bicycle specific traffic signals is for cycle track applications where bicycles move in contraflow to vehicle movements. Comfort and convenience of the bicycle mode may be improved by utilizing bicycle specific traffic signals to better communicate the disposition of right of way at the intersection.

Figure 8 - Example Bicycle Signal Face

(Source: California MUTCD 2014 Edition Figure 4D-112)

From a signal timing perspective bicycle specific traffic signals offer an opportunity to specifically address the operating characteristics of bicycles and support the display of signal timing intervals that are appropriate to their needs and operational constraints; minimizing the impacts on automobiles and pedestrians. A number of jurisdictions utilize standard Red, Yellow and Green balls in addition to signage to indicate that a signal face is intended for bicycles.

3 CLASSIFYING TRAFFIC SIGNAL OPERATIONAL STRATEGIES FOR BICYCLES

Chapter 2 provided the research background and current practices for treatment of bicycles at signalized intersections. Chapter 3 builds on the foundation of chapter 2 by organizing the strategies into tiers based on their functional objective. Chapter 4 will present a framework for implementing Traffic Signal Operational Strategies for Bicycles (TSOSB). An understanding of the potential application of the framework can be gained by observing how TSOSB for bicycles are being used among several prominent agencies that have a distinction for prioritizing the bicycle mode. Section 3.1 sets the stage for discussing TSOSB by first establishing a set of operations objectives to which TSOSB can be connected to. A targeted interview of several prominent agencies was completed is presented in section 3.2 to gain insight on how TSOSB are currently being applied in practice. The framework presented limits the solution space for TSOSB to traffic signal phasing, timing, and logic features that are currently available and in use. Additionally, the framework will focus on facilities that have been designated as official bicycle routes, placing emphasis on, on-street bicycle lanes. The designation of a roadway as a bicycle route communicates to the public that a reasonable level of special accommodations for bicycles can be expected. Infrastructure investments to reserve roadway space for bicyclists demonstrate a commitment to improve safety, comfort, and convenience and an underlying goal of increasing bicycle ridership.

3.1 OPERATIONS OBJECTIVES

The inclusion of a special signage, bicycle parking, marked bike lanes, green pavement and so forth, seems to formalize an invitation to bicyclist that some level of accommodation can be expected on these designated routes. This special invitation, in combination with the know vulnerability of bicycles from a safety perspective, to some extent should resolve competing operational objectives between bicycles and automobiles, in favor of the bicycle. Inclusion of marked bicycle lanes may require a tradeoff between the automobile mode LOS and bicycle mode LOS. Analysis methods to evaluate the tradeoffs between space dedicated to automobiles and bicycles tends to focus on flow and capacity effects and does not adequately account for the needs of the bicyclist in terms of their skill level and how this relates to their comfort, convenience, and willingness to use on-street bicycle lanes. Uncertainty surrounding widely accepted analysis methods is likely to produce uncertainty in how to prioritize operational objectives. The prioritization of transportation operational objectives, whether documented or not, becomes evident by observing the design and operation of the facility. Bicycle facilities that do not provide continuity in the LOS, safety, comfort, and convenience are discontinuous and detract from the bicyclist's sense of safety, comfort, and convenience and are likely to negatively impact ridership (Nuworsoo & Cooper, 2013). Additionally, bicycle facilities that are underutilized invite scrutiny about their value in terms of both capital cost and the costs to automobile mode in terms of level of service.

Research completed and underway is providing more insight into the needs and operating characteristics of bicycles and the Level of Service tradeoffs that must be made as competing operational objectives between automobiles and bicycles are resolved. Clarity of objectives is a philosophy that orients the design and operation of transportation facilities with the needs and expectations of users; and is achieved when the objective of the operation is perceptible and consistent with the user's expectations (FHWA, 2009). The need to make tradeoffs in the quality of service provided to the automobile and bicycle mode must be anticipated as the operational objectives associated with each mode are prioritized and balanced to resolve competition among objectives. Competing objectives must be resolved or we risk violating the principal of clarity of objectives. Failure to resolve competing objectives may produce conditions that are not favorable to the automobile or bike mode which ultimately undermines the achievement of any objectives. Commitment to clarity of objectives for on-street bicycle facilities first means providing adequate space and operational strategies to reduce the Level of Traffic Stress these users experience by providing for safety, comfort, and convenience. TSOSB have largely been bypassed during the implementation of regional bicycle networks resulting in gaps to bike mode safety, quality of service, comfort and convenience (Pucher, Dill, & Handy, 2009). Examples of core objectives for the bicycle mode:

1) Provide safe and equitable accommodations for bicycles at all links and nodes in the bicycle network.
2) Provide a comfortable and convenient riding experience in on-street bicycle facilities that is consistent with bicycle riders in the Interested but Concerned classification of riders.
3) Minimize the number of stops and delays for the bicycle mode.

3.2 THE CURRENT USE OF TRAFFIC SIGNAL OPERATIONAL STRATEGIES FOR BICYCLES

A questionnaire was distributed to 14 agencies in the United States to assess the relative implementation of traffic signal timing features to improve the accommodation of bicycles. The selection of agencies to receive the questionnaire was based on data indicating significant implementation of on-street bicycle lanes, provided in the 2014 Bicycling and Walking Benchmarking Report. After initial screening of the Benchmarking Report data, a search was conducted to determine the availability of each agency's Bicycle Master Plan. A review of each agency's Bicycle Master Plan was completed to gain insight about the agencies approach to, existing and planned implementation of bicycle infrastructure. A total of 5 agencies responded to the questionnaire, a 36% response rate. The full text of the questionnaire is included in appendix A. Table 4 below summarizes the responses to the questionnaire; Atlanta is added to provide later context to the case study provided later.

Table 4- Summary of Questionnaire Responses

Agency Location	% of Commuters Bike to Work	Bike Min Green	Bike Clearance	Detection	Leading Bicycle Interval	Passage Time	Short Cycle Lengths	Acutated Coordintated	Bike Green Wave	Exclusive Bike Phases
Portland, OR	6.10%	Proposed, Not in Use	Proposed, Not in Use	In Use	In Use	In Use	In Use	In Use	In Use	In Use
Washington, DC	2.90%	In Use	In Use	In Use	In Use	Proposed, Not in Use	In Use	Not Aware	Proposed, Not in Use	In Use
Mesa, AZ	1%	Proposed, Not in Use	Not Aware	In Use	Proposed, Pending	Proposed, Not in Use	Aware, Not Proposed	In Use	Aware, Not Proposed	Aware, Not Proposed
New Orleans, LA	2.30%	Aware, Not Proposed	Not Aware	Proposed, Pending	Aware, Not Proposed	Aware, Not Proposed	Aware, Not Proposed	Not Aware	Proposed, Rejected	Aware, Not Proposed
Salt Lake City, UT	2.50%	Proposed, Rejected	Aware, Not Proposed	Proposed, Pending	Proposed, Not in Use	Aware, Not Proposed	Proposed, Rejected	No Response	Proposed, Not in Use	Proposed, Rejected
Atlanta, GA*	1.10%	Not in Use	Not in Use	In Use	Not in Use	Not in Use	Not in Use	Not in Use	Not in Use	Not in Use

Figure 9 Summary of Questionnaire Response - Bicycle Min Green below, provides a summary of survey responses concerning the use and awareness of bicycle minimum green. Of the agencies responding to the questionnaire, only 1 of the 5 is currently using bicycle minimum

green. The questionnaire was limited to a sample of agencies with significant percentages of on-street bicycle lanes. Given the progressive nature of these agencies towards prioritizing bicycle but is an indicator of a very low utilization of bicycle minimum green nationally.

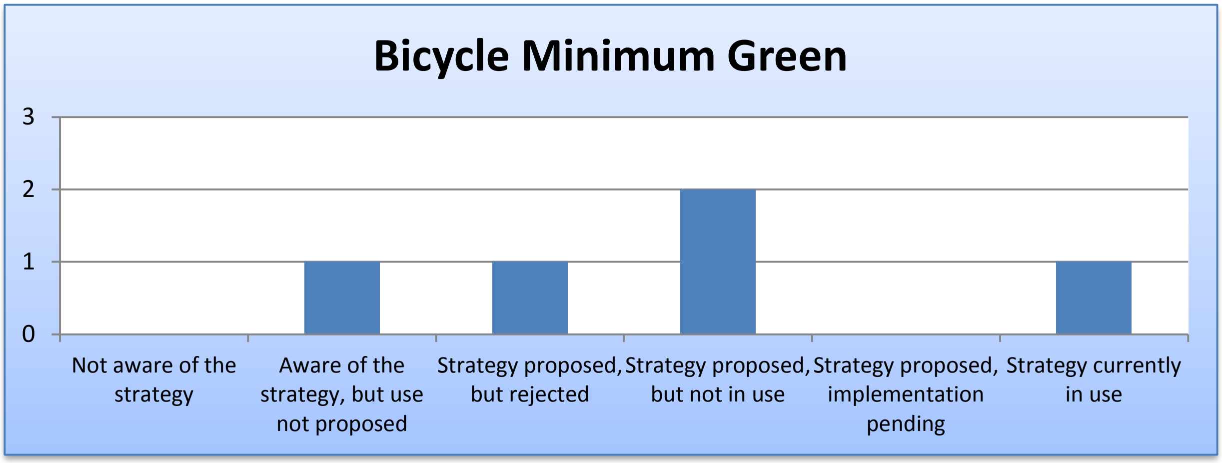

Figure 9 Summary of Questionnaire Response - Bicycle Min Green

Figure 10 below summarized responses to the questionnaire with respect to bicycle clearance time. Only 1 of the 5 agencies is currently utilizing Bicycle Clearance Time suggesting a relatively low recognition of the benefits and requirements of this TSOSB.

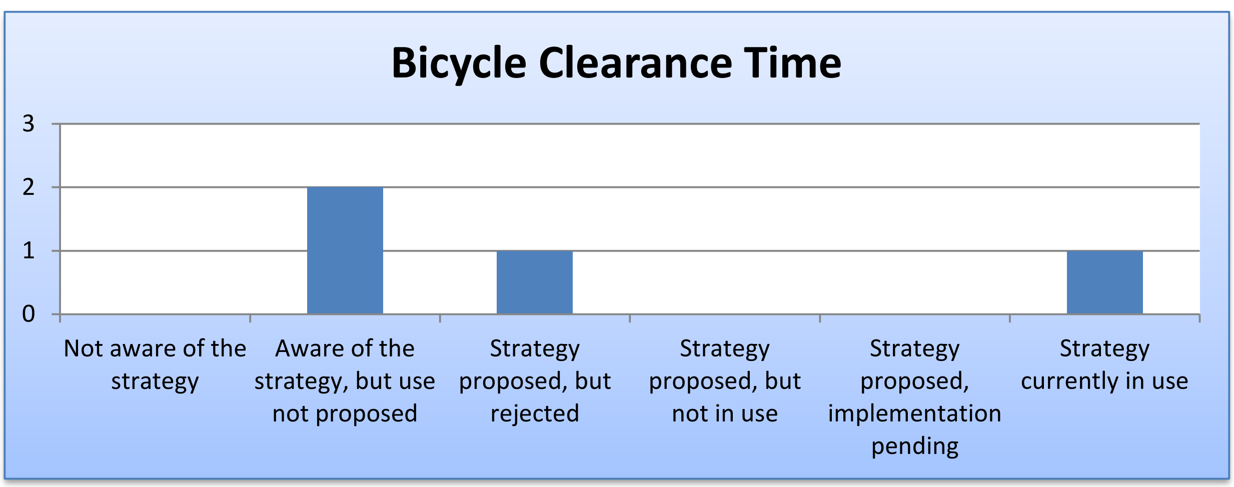

Figure 10 Summary of Questionnaire Response - Bicycle Clearance Time

Based on response to the questionnaire summarized in Figure 11 below, it appears that awareness of and use of bicycle detection could be fairly prominent in the United States.

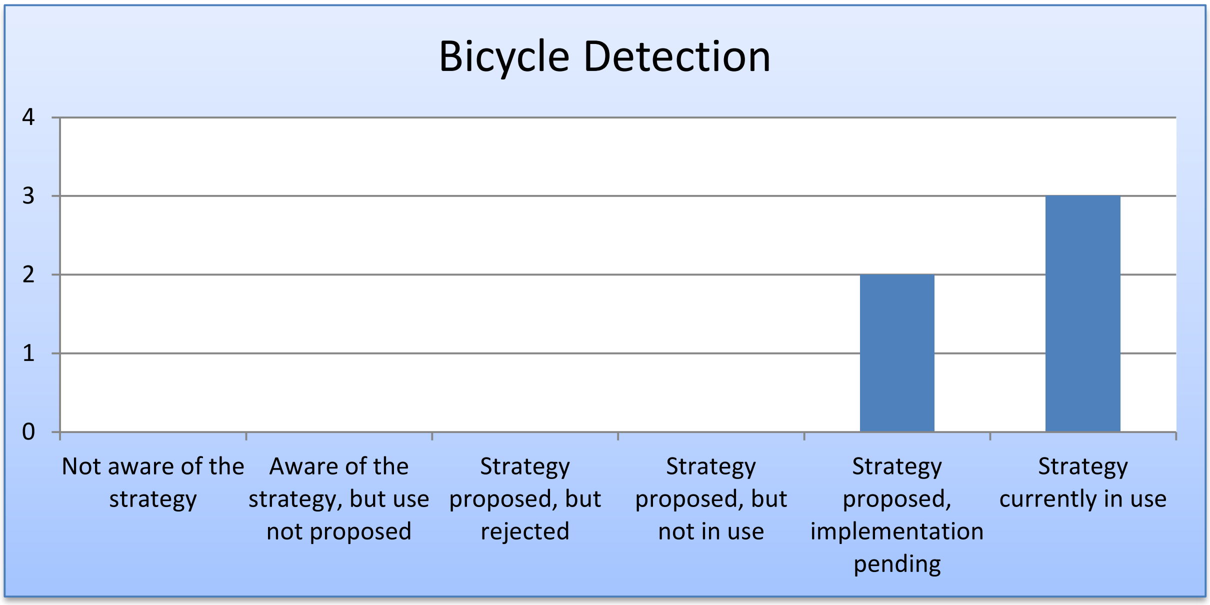

Figure 11 Targeted Survey Response, Awareness and use of bicycle detection

The awareness and use of short cycle lengths among key agencies are summarized in Figure 12 below. All of the agencies were aware of the strategy but only 2 of the 5 have actually implemented it to reduce delays to bicycles. This could indicate on a broader scale awareness of the strategy but limited implementation.

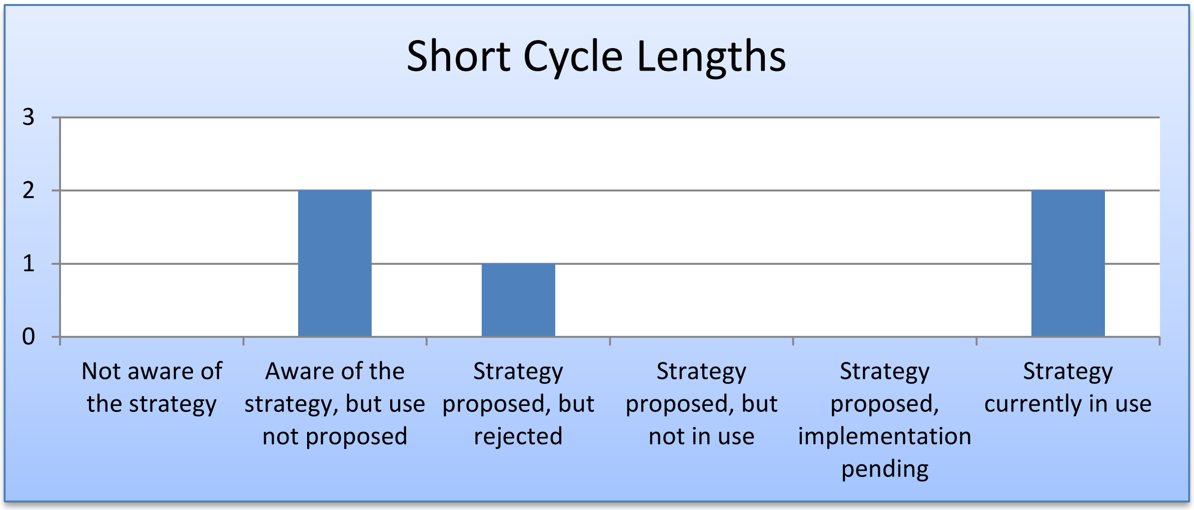

Figure 12 Summar of Questionnaire Responses - Use of Short Cycle Lengths to Reduce Bicycle Delay

Figure 13 summarizes questionnaire responses on the topic of bicycle passage time to improve the comfort and convenience of the bicycle mode by reducing the delay experienced at signalized. Only one of the five respondents to the survey is currently using the strategy. This strategy is contingent on the implementation of bicycle detection, an enabling strategy for bicycle passage time.

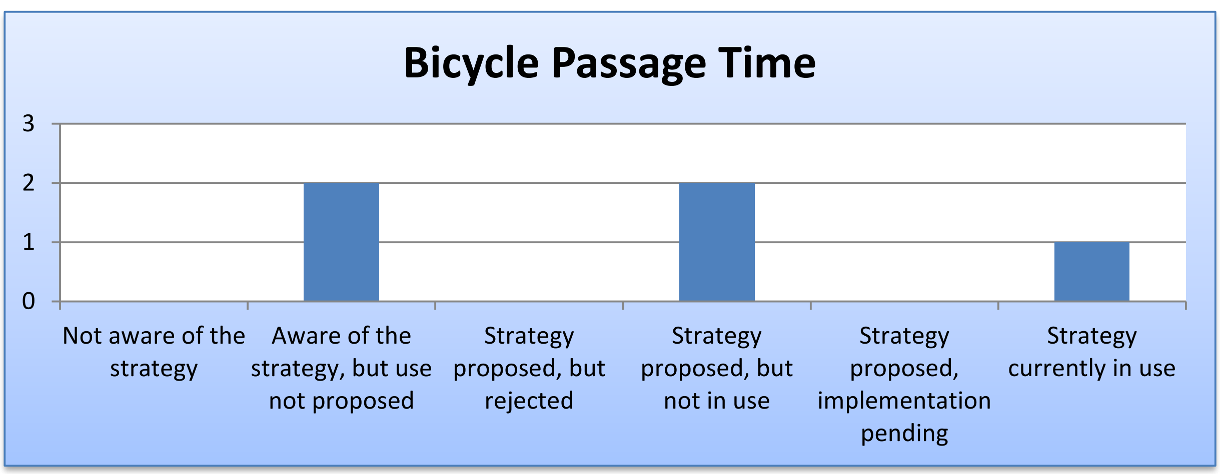

Figure 13 Targeted survey response, awareness and use of bicycle passage time

The responses to the question concerning the use of Actuated Coordinated Operation to reduce delay are summarized in Figure 14 below. The responses suggest that the strategy is not widely used, but is growing in recognition. Only one of the 5 agencies is currently using the feature; two agencies have proposed implementation; which might indicate that expanded use of this feature can be anticipated.

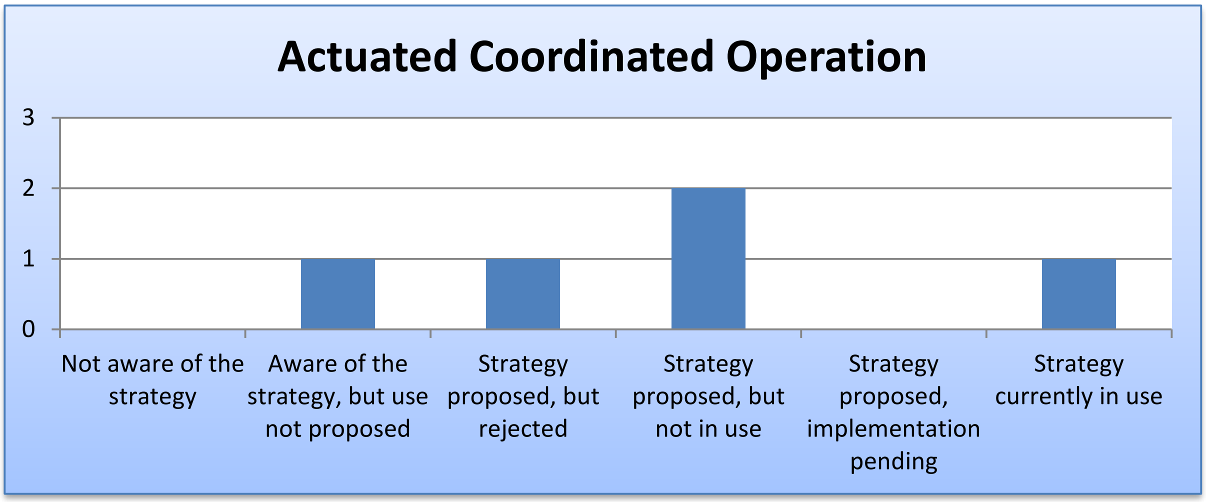

Figure 14 Targeted survey response, awareness and use of actuated coordinated operation

Figure 15 summarizes the response to a survey question about the use of bicycle progression. The response suggest that the use of bicycle progression is growing with one of the five agencies responding currently using the strategy and two proposing its use. All agencies responding to the survey indicated awareness of the strategy.

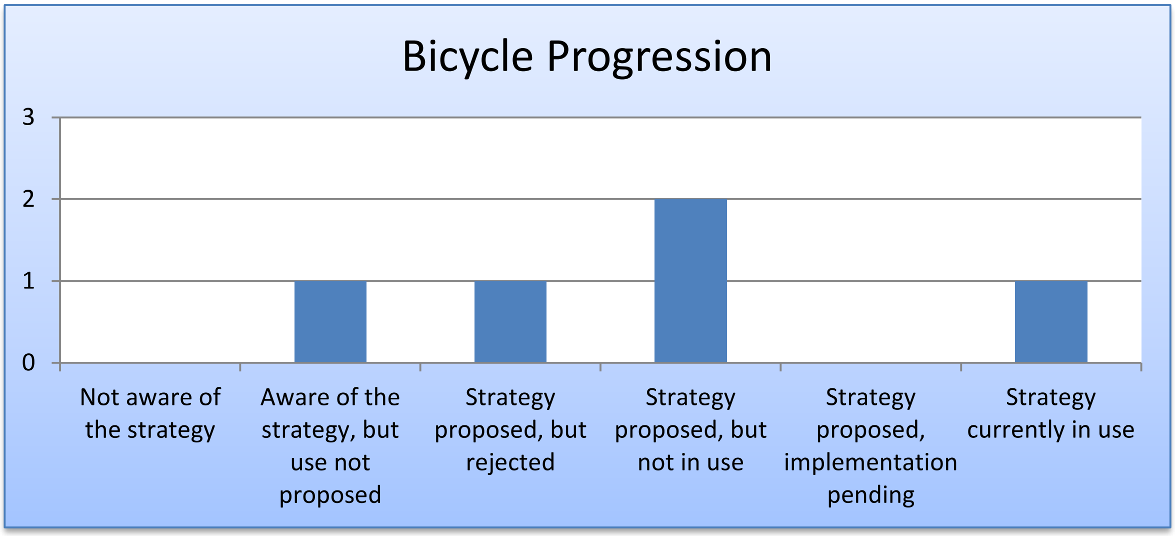

Figure 15 Targeted survey response, awareness and use of bicycle progression

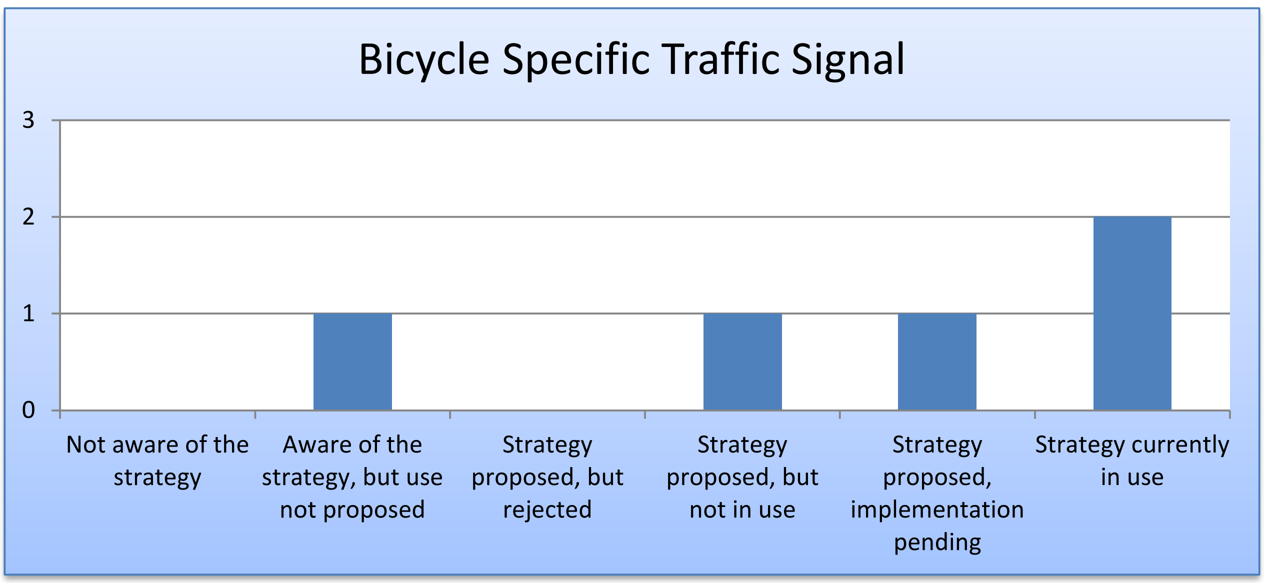

Figure 16 - Targeted survey response, awareness and use bicycle specific traffic signal

Figure 16 above, summarizes the responses to a survey question to assess the use of bicycle specific traffic signals. Based on the responses there is both awareness and use of specific traffic signals to improve the movement of bicycles where the positive control of bicycles is better accomplished through the use of specialized traffic signals as shown in Figure 16 above.

3.3 ORGANIZING TRAFFIC SIGNAL OPERATIONAL STRATEGIES INTO TIERS

Table 3 below, organizes Traffic Signal Operational Strategies for Bicycles into a three tier structure. The table places each of the TSOSBs in tier and identifies its primary functional objective based on the related vehicle function of the strategy. Each tier and an assessment process are provided in the sections that follow. In Table 3 below, the primary functional objective of each strategy is indicated with a check mark. These classifications are flexible and not based on study conducted in this research; potential secondary functional objectives are indicated with an asterisk. The tier structure is preliminary classification of TSOSBs.

Table 5 Summary of Traffic Signal Timing Operations Strategies for Bicycles

Tier	TRAFFIC SIGNAL TIMING OPERATIONAL STRATEGIES FOR BICYCLES	Safety	Comfort & convenience	Bike Mode Preference
TIER 1	Bicycle minimum green time	✓	*	
	Bicycle Crossing Time	✓	*	
	Bicycle detection	✓	*	*
TIER 2	Short Cycle Lengths to minimize bicycle delay		✓	
	Actuated coordinated operation		✓	
	Bicycle passage time or extension	*	✓	
	Turning Movement Restrictions	*	✓	
TIER 3	Bicycle Green Wave		✓	✓
	Bicycle Specific Traffic Signals	*	✓	✓
	Exclusive Bicycle Phases	*	✓	✓

✓ - Primary Effect, * Secondary Effect

This tier classification can be applied in the context of operations objectives to identify strategies that can be readily implemented to address safety, comfort and convenience or bike mode preference. It must be noted that the implementation of traffic signal operational strategies is currently very limited and in many respects the needs of bicycles at signalized intersections is not well understood. The classification of strategies into a tier and the application of each tier to safety, comfort and convenience and bike mode preference are preliminary and intuitive. No detailed evaluations or research was located describing the specific impact of the TSOSB included in this research.

3.4 TIER 1 – SAFETY STRATEGIES

Safety is the highest priority of traffic signal design, operations, and maintenance activities. From the bicyclist's perspective safety, or the perception of safety, plays a major role in the Level of Traffic Stress experienced on a particular route (Mekuria, Furth, & Nixon, 2012). Crash history is a relevant measure of safety that is difficult to assess given the long time periods that are typically required to obtain a statistically significant sample in the case of bicycle crashes. The Atlanta Regional Council noted that the vast majority of crashes involving bicycles are the outcome of high risk behavior such as failing to yield or violating traffic signals and therefore crash history is not necessarily an indicator of dangerous conditions (Atlanta Regional Commission, 2007).

A study of bicycle facilities in Washington, D.C. evaluated crash history before and after the installation of bicycle facilities and also incorporated an observational analysis which involved video recording of intersections to visually quantify cyclist behavior including compliance, near misses, and emergency stops (Goodno, McNeil, Parks, & Dock, 2013). Due to the uncertainty of crash history as an indicator of dangerous or high risk intersections, this data is not included in the safety assessment.

3.4.1 TIER 1 – SAFETY ASSESSMENT

The first tier assessment applies minimum green, crossing time, and bicycle detection criteria to score each intersection approach. The tier 1 composite score is assigned by summing the scores for each intersection approach for all three of the assessments. Each approach has a maximum potential score of 28, 25 for safety and 3 for comfort and convenience. For an intersection that has bicycle lanes on two approaches, the maximum score for the intersection will be 56. For an intersection with bicycle lanes on four approaches, the maximum score is 112. The tier 1 score is intended to provide a relative measure of the potential level of safety improvement that can be achieved at the intersection by improving the signal timing. Figure 17, Figure 18 and Figure 19 provide flow charts to guide the assessment and scoring of each intersection approach for tier 1. Based on the outcome of the assessment, chapter 2.6 should be referenced to select TSOSB that should be considered for evaluation in response to the assessment to improve the safety of the intersection for the bicycle mode.

3.4.1.1 BICYCLE MINIMUM GREEN ASSESSMENT

Figure 17 provides a flow chart for assessment of Bicycle Minimum Green. The process suggests that it is imperative that all signalized intersections provide minimum green timing. Fixed time intersections should provide minimum green for approaches with on-street bike lanes each time the phase is displayed. Actuated intersections are expected to provide minimum green time whenever a bicycle call is placed for the respective phase. The criteria is straight forward; however it does not account for factors like grade, multiple bicycles, presence of pedestrians or leading bicycle intervals.

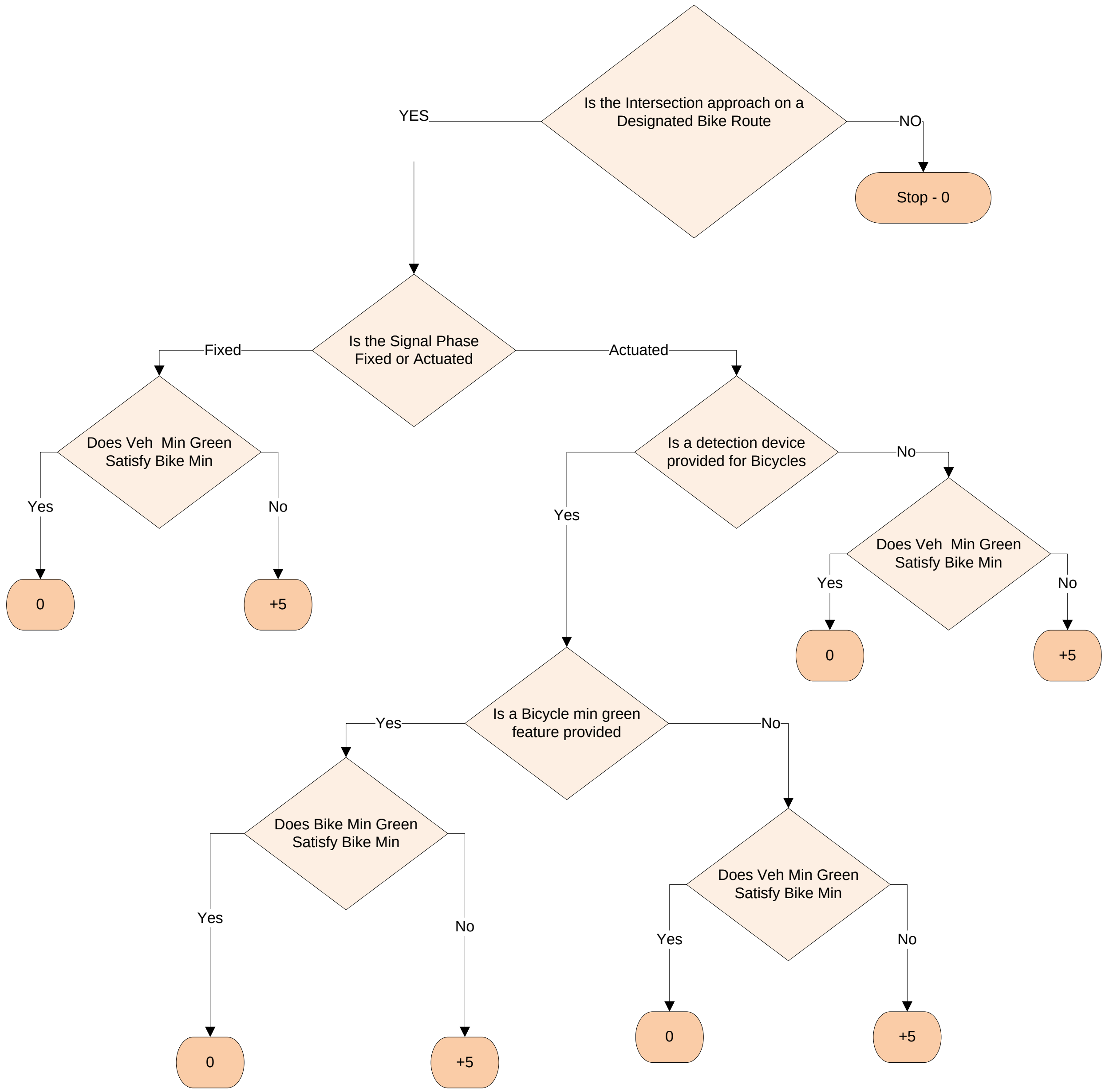

Figure 17 - Tier 1 Minimum Green Assessment Flow Chart

3.4.1.2 BICYCLE CROSSING TIME ASSESSMENT

The bicycle crossing time assessment evaluates each intersection approach equipped with an on-street bicycle lane for adequate provision of crossing time. The crossing time is a function of the width of the intersection and should be measured from the stop bar of the intersection to the far side of the crosswalk on the other side of the intersection. The assessment is fairly in flexible assigning a score of +5 regardless of the level of deficiency of the crossing time. There is no gradation in the score and minor deficiencies of say 0.1 sec are rated equally to deficiencies of 2.0 seconds. Additional research could improve the assignment of scoring.

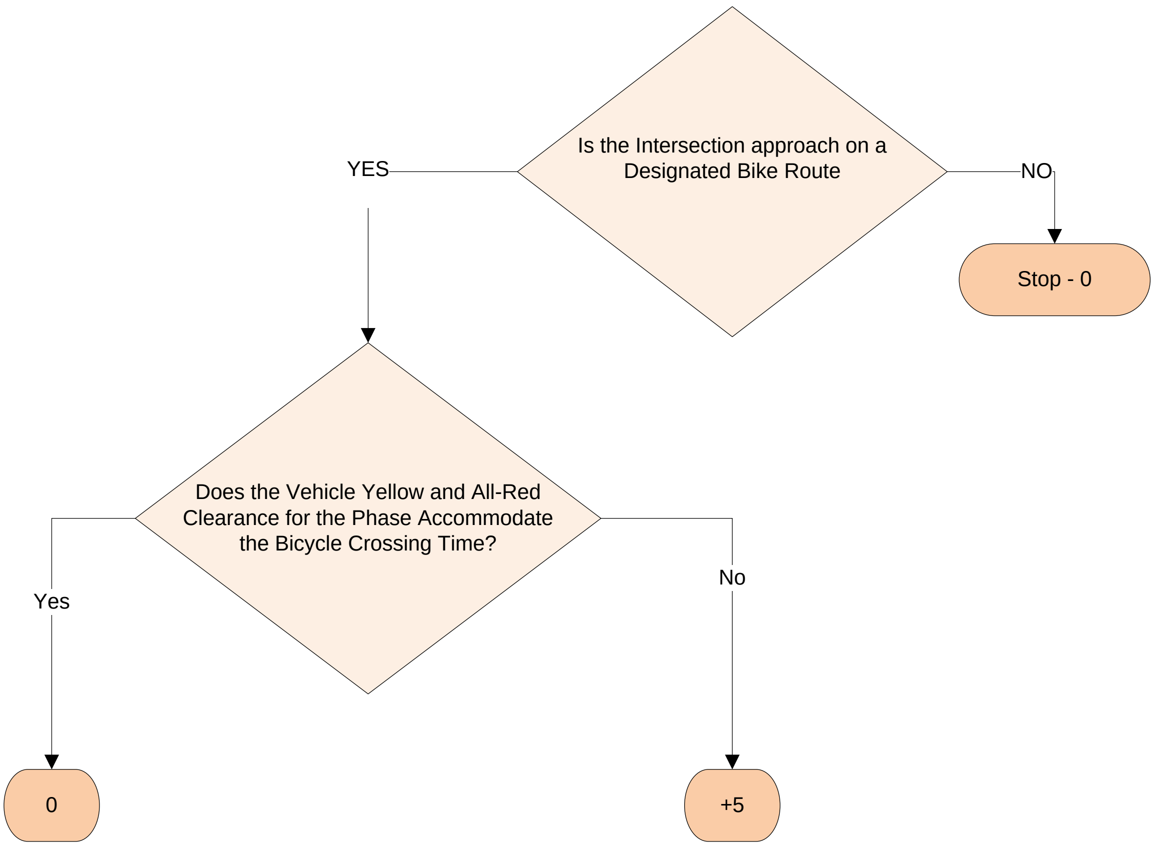

Figure 18 Tier 1 - Assessment of Bicycle Crossing Time

3.4.1.3 BICYCLE CROSSING TIME ASSESSMENT

The bicycle detection assessment process is captured in Figure 19. The assessment is strongly biased towards the capability of detecting bicycles both actively and passively; which begins to lean into a preference criteria. The scoring is not consider the proper marking and signage for bicycle detection, push buttons or the configuration of signal timing parameters. Additional research is necessary in this area and anticipated given the recent requirement in the CA-MUTD to require bicycle detection for any new or significantly modified intersection detection system.

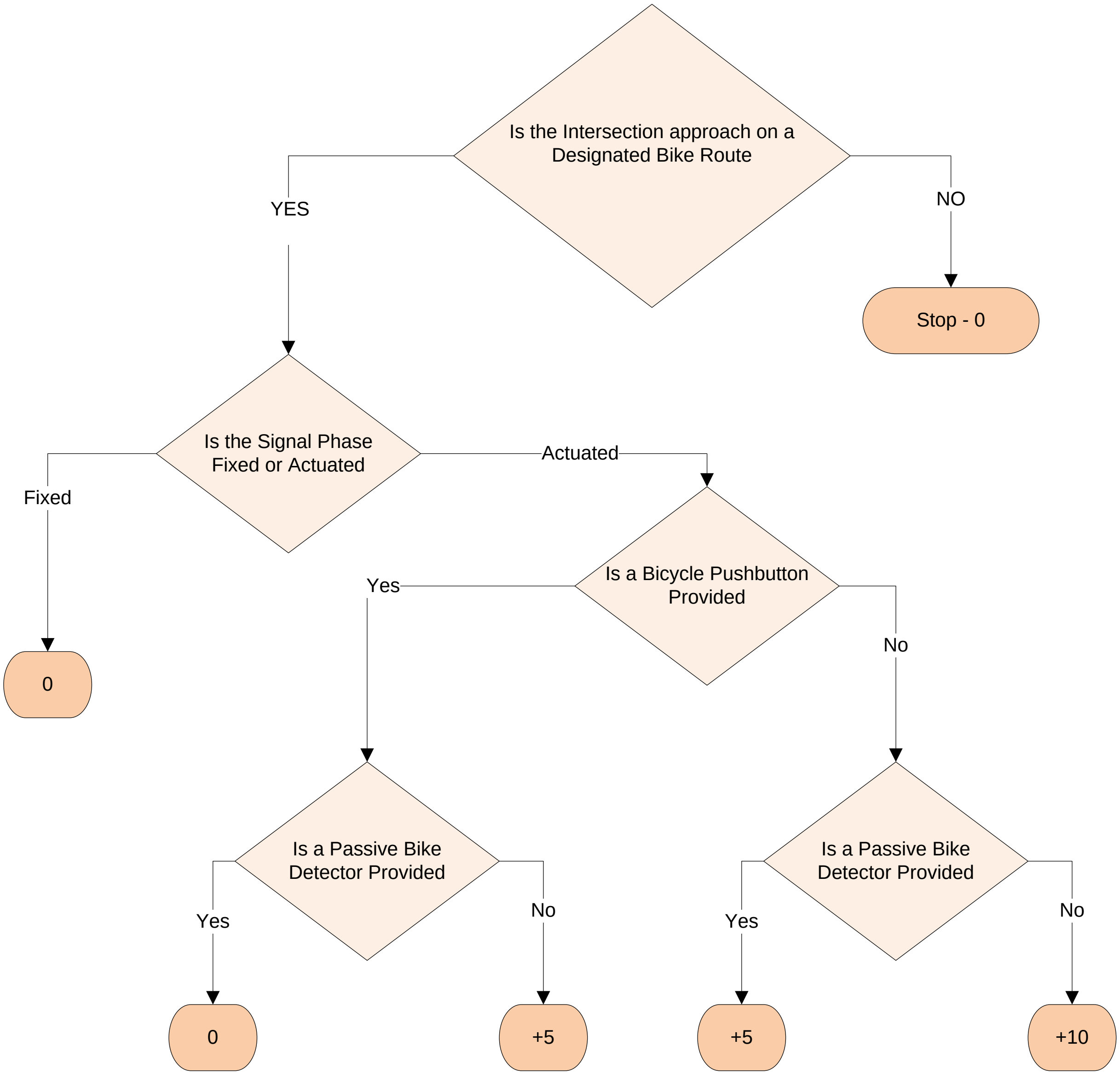

Figure 19 Tier 1- Assessment of Bicycle Detection

3.5 TIER 2 – COMFORT AND CONVENIENCE STRATEGIES

Comfort and convenience address the perceptions about the safety and the sensitivity of the facility design to meet the users' needs. Bicycle ridership increased by 200% on Pennsylvania Avenue in Washington, DC after bicycle facilities were installed to improve the comfort and convenience of the facility (DDOT, 2012). Bicyclists are more likely to perceive satisfactory levels of safety comfort and convenience when bicycle facilities are designed to meet objectives that are consistent with the bicycle mode. Examples of core objectives for the bike mode are provided in section 3.1. Bicycle detection that is accurate and clearly guides bicyclists on how to actuate detection addresses comfort and convenience needs. Comfort and convenience are characteristics of bicycle facilities that are frequently associated with increasing bicycle ridership among women and imply safe and efficient facilities that impose minimal delays and provide continuity of service along on-street bicycle facilities (Alliance for Biking and Walking, 2014). The Highway Capacity Manual (HCM) provides a single quantitative method to evaluate bicycle delay that accounts for the allocation of effective green time relative to cycle length. However, bicycle delay is not included in the HCM LOS analysis for the bike mode at the link or intersection level. The HCM equation for bicycle delay at signalized intersections follows:

$$d_b = \frac{0.5C(1-\frac{g_b}{C})^2}{1-\min[\frac{v_{bic}}{c_b}, 1.0\,]\frac{g_b}{C}}$$ (Transportation Research Board, 2010)

Where

d_b = Bicycle Delay (s),
C = Cycle Length (s),
g_b = Effective Green Time (s),
v_{bic} = bicycle flow rate (bicycles/h),
c_b = capacity of the bicycle lane (bicycles/h),

The delay for each signalized intersection will be computed to assign a delay rating.

3.5.1 TIER 2 – COMFORT AND CONVENIENCE ASSESSMENT

The tier 2 assessment requires computation of the HCM 2010 bicycle delay for each intersection approach. The scoring criteria will assign a maximum score of 3 for each intersection approach equipped with a bike lane. A flow chart to guide the scoring of the tier 2 assessments for each intersection approach is provided in Figure 20. A composite tier 2 score is developed by summing the scores for each intersection approach to provide an indicator of the potential to improve the comfort and convenience of the intersection. Traffic signal timing strategies that may be evaluated to improve bicycle comfort and convenience are available in Chapter 2.6. The assessment scoring is based on HCM language in Chapter 18 that indicates a higher tendency of bicycle violations when delay exceeds 30 seconds. Similar to other measures the bicycle delay assessment is a relative measure intended to rate intersections within a group and should not be used as a measure of quality of signal timing.

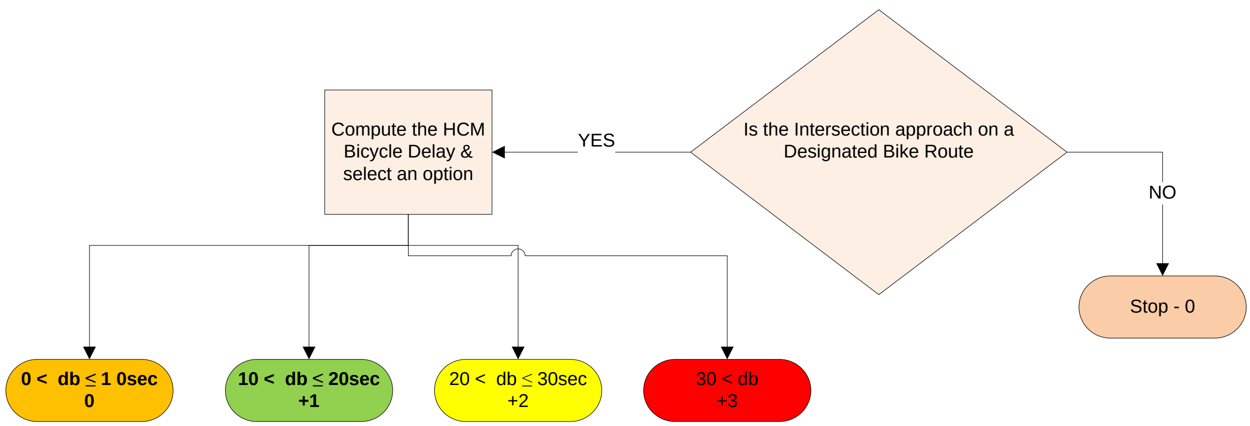

Figure 20 Tier 2 - Bicycle Delay Assessment

3.6 TIER 3 – BIKE MODE PREFERENCE STRATEGIES

Strategies in Tier 3 are oriented around clearly communicating that a facility prioritizes bicycle above the automobile mode. These strategies maximize the safety, comfort and convenience of the bike mode by reducing the speed, space and access of automobiles and potentially pedestrians.

3.6.1 TIER 3 - BIKE MODE PREFERENCE ASSESSMENT

The Tier 3 assessment is not based on an evaluation of demand or geometric considerations. The preference for the bicycle mode is a policy decision and consistency should be demonstrated at all levels of planning, design, operation and maintenance to achieve bicycle operations objectives. The Bicycle Master Plan for the jurisdiction should be reviewed to validate the desire for bicycle preference. Once Bicycle preference has been established, comprehensive strategies should be implemented to achieve this outcome. There are several jurisdictions where the desire to provide preference to bicycles throughout the entire bicycle network or for specific corridors within the network are documented in the Bicycle Master Plan (City of Davis , 2009) (Portland Bureau of Transportation , 2010) (DDOT, 2012).

4 TRAFFIC SIGNAL OPERATIONAL STRATEGIES FOR BICYCLES IMPLEMENTATION FRAMEWORK

As discussed earlier, it is important for stakeholders and users the on-street bicycle networks to be able to clearly ascertain the functional and operational objective of bicycle facilities and signalized intersections within the bicycle network. When conflicting objectives are left unresolved safety and efficiency could be compromised and the value of transportation planning, design, operation and maintenance efforts can be undermined. To avoid these issues it is imperative that investments in bicycle facilities are placed and serve the intended users equitably and meet their expectations for appropriate accommodation of safety and efficiency. The methodology described here provides a Demand Based Approach to identify and prioritize zones at the census tract level with a moderate expectancy of producing bicycle work or school trips. An integrated land use and bicycle travel data set supports analysis of census tracts within an area to develop a measure characterized in this research as strength of bike to school or work. Once priority zones are identified, the traffic signals with each zone can be evaluated to reveal gaps in safety, comfort and convenience or bicycle mode preference that can be improved with the implementation of TSOSB. The outcome of the methodology is a ranked list of signalized intersections within priority zones with gaps in bicycle quality of service. Application of TSOSB in high priority zones is intended to improve safety, comfort, convenience, or preference for the bike mode to produce more comprehensive bicycle facilities. Comprehensive bicycle facilities go beyond simply reserving minimal amounts of space on the roadway in the form of on-street bicycle lanes. Comprehensive bicycle facilities employ a diverse set of strategies aimed at prioritizing the bicycle mode and include policies and programs to minimize the Level of Traffic Stress (LTS) (Active Living Research, 2013).

4.1 CONSTRUCTING THE INTEGRATED LAND USE AND BICYCLE TRAVEL DATASET

As articulated earlier, it is important to place transportation infrastructure in locations and amongst users that offer the greatest potential return on investment. Many of the Bike Master Plans reviewed in the context of this research, described the use of a Latent Demand Model to estimate the potential for production of bicycle trips. When a Demand Based Approach has not been completed to identify and prioritize the location of bicycle facilities, it may be advantageous to conduct a brief evaluation of land use to identify and prioritize zones for implementation of TSOSB. One way to conduct a brief Demand Based Approach is to develop an integrated land use and bicycle travel dataset. A regression analysis can be conducted on the dataset and then applied to the study area to identify critical zones for implementation of TSOSB.

The following process was used to develop an integrated land use and bicycle travel behavior dataset. Land use data was obtained from the US Census Bureau American Community Survey, at the census tract level. Person level frequency of bike to work data was obtained from the 2011 Atlanta Regional Travel Survey. The first step in the process is to aggregate of the person level frequency of bicycle to work or school data, to the household level. With bicycle data now at the household level, a strength of bicycling variable based on the frequency of bicycling to work or school can be developed by census tract, summarizing all of the household level data. The strength of bicycling data was then normalized by the area of the census tract to provide frequency of bike to work or school as a density function. The final step in the integration was to join land use and household bicycle travel data, by census tract level, to produce the integrated land use bicycle travel dataset. The key land use variables selected for analysis at the census tract level included:

- Total commuting for work with sub categories of drive alone, carpool, transit and walk to work;
- Total employment with subcategories of retail employment;
- Number of Households;
- Median Income;
- Population;
- School Enrollment with sub categories of over the age of 3 school enrollment, over the age of 18 school enrollment, and College enrollment.

The IBM SPSS Statistics software was used to conduct a linear regression of the integrated land use and bicycle travel dataset. A number of models were developed to correlate the land use variables to coefficients that predict the dependent variable and census tract frequency of bicycle trips for work or school. The regression produced coefficients for each independent variable included in the model to support prediction of strength of bicycling for each census tract in the study area; the model is presented in Chapter 5. The end product of the process is a comparison of the relative strength of biking among all census tracts in the study area to support selection of census tracts that are most likely to produce bike trips. A caution for this method is bicycle data at the census tract level is a relatively weak variable due to small sample size. Regional travel surveys may provide an increased sample of bike data. For the purpose of conducting a comparative analysis of census tracts this method is sufficient and provides predicted values for census tracts in which no bicycle data is recorded.

4.2 ASSESSING POTENTIAL TRAFFIC SIGNAL TIMING IMPROVEMETNS

After comparison of the relative strength of bicycling in each analysis zone, one or more zones should be selected for additional analysis. The signalized intersections within each zone will be assessed according to criteria in all three tiers. The first tier assesses several safety related criteria; the second assesses comfort and convenience based on bicycle delay; the last assesses bicycle mode preference. Each Tier assessment process and scoring criteria was developed as part of this research and is an area where additional study is needed. The Tier 1 assessment is oriented around safety and the weighting of the score reflects the priority of safety relative to comfort and convenience or bicycle preference. The score for each intersection is a relative measure of the potential level of improvement amongst the intersections in the group. The score should be interpreted within the group to rank the intersections. For example, an intersection with a score of 40 demonstrates a much higher return on investment to improve safety, comfort and convenience than an intersection with a score of 10. The scores should not be used outside of a comparative context without additional research to consider sensitivity issues and the impact of the strategies themselves.

5 CASE STUDY - CITY OF ATLANTA

The Demand Based Approach and intersection ranking methodology described in chapter 4 was applied to the City of Atlanta to validate the utility of the methodology. The City of Atlanta updated its Bicycle and Pedestrian Walkways Plan in 2007 using a Demand Based Approach for identifying the condition of over 600 miles of roadway to accommodate pedestrians and bicycles using a bicycle Level of Service mode. A Latent Demand Model (LDM) was then applied to prioritize the implementation of strategic bicycle corridors. The LDM model includes land use and travel behavior data at a high level and applies the principles of a gravity model to identify the intensity of paths between each attractors and generators (Atlanta Regional Commission, 2007). The City of Atlanta currently has 62 miles of on-street bicycle lanes with minimal implementation of TSOSB. The case study applies the chapter 4 methodology to identify and study a single high priority zone within the City of Atlanta and develops a ranked list of signalized intersections within the zone for consideration of TSOSB.

5.1 DEVELOPMENT OF CITY OF ATLANTA INTEGRATED LAND USE AND BICYLE TRAVEL DATASET

The 2011 Regional Travel Survey provided data to represent household level frequency of walking or biking to work or school. For the entire regional dataset, bike mode accounted for only 0.3% of the modes selected, 0.4% of work trips and 0.5% of school trips. (Atlanta Regional Commission, November 2011). An integrated land use and bicycle travel behavior integrated dataset was developed for the City of Atlanta by extracting land use and regional travel data from the American Community Survey (ACS) and Regional Travel Survey data provided by the

Atlanta Regional Commission. The survey data was collected from 10,278 households, Traffic Analysis Zones (TAZ) were included in the household information and was used as the key variable to join the travel survey data with the land use data at the census tract level. The United States Census Bureau collects data to produce population and housing information via an annual survey that is distributed to about 3.5 million households annually (US Census Bureau, 2015). The literature review provided the theoretical background to select a number of land use variables that have demonstrated significant relationships to bicycle ridership. The selected variables include total and subsets of data in the following categories: Population, School enrollment, Employment, Transit accessibility, and Commuting.

The strength of bicycling variable (SBTW) was developed by manipulating person level responses to the Atlanta Regional survey requesting information about frequency of bicycle travel for work or school purposes (Atlanta Regional Commission, November 2011). The survey provided a question at the person level requesting the frequency of travel to work or school by walking or biking. This variable was recorded in the PERSON table as FBKTW, with the following potential responses:

1	0 Times (Never)
2	Once or Twice
3	3 or 4 Times
4	5 or more Times
8	DK (Don’t Know)
9	RF (Refusal)

The FBKTW variable was manipulated to remove all records that contained “8” or” 9” as these were not considered valid responses. Responses recorded as “1” were set to zero indicating that frequency of travel by bicycle for work or school did not exist. The response of “2” was converted to 1 representing a low strength of bicycling frequency of once or twice. The response of “3” was converted to 2, representing a moderate level of bike to work or school frequency (3 or 4 times). The response of “4” converted to 3 representing a strong frequency of bicycle travel for work or school (5 or more). It should be noted that the survey question blended interval ranges to produce an ordinal scaled response. Conversion of the numbers creates the appearance of interval data however a much more rigorous statistical process is required to complete the conversion in a reliable manner. While the analysis treats the variable as interval, caution and awareness of this is exercised in the interpretation of the results.

The dataset contains strength of bicycle travel by household that is summed across the census tracts. The dependent variable, SBKTW represents the strength of bicycling within each census tract providing the capability for comparing bicycle travel among all census tracts in the study area. The strength of bicycling becomes a function of density of census tracts relative to one another effectively showing a preference for more densely populated areas as they will result in census tracts of smaller areas.

The intent of the integrated land use and bicycle travel behavior dataset is to provide the basis for a regression analysis that allows the prediction of strength of bicycling for all census tracts within the City of Atlanta. Census tracts were used as the geospatial boundary for analysis zones and all variables were normalized to the census tract area in acres to develop density functions as appropriate. Data for each land use variable of interest was downloaded from the ACS by census tract. Table 5 provides a summary of the variables, and related descriptive statistics. The dependent variable selected was Strength of Bicycling Density at the census tract level. The N represents the number of census tracts within the study area. The study area was initially the 20 county Atlanta Metropolitan area. The study area this was reduced to exclude census tracts with a frequency of bike to work with responses in the survey of 8, 9 or 0. Inclusion of these values was evaluated to determine the effect on R-Squared; because no explanatory value was gained these data points were removed from the model reducing N to 248.

	N	Mean	Std Deviation	Minimum	Maximum
Strength of Bicycling Density	248	0.02565846	0.055873819	0.0001867	0.49472853
Commute by Walking Density	248	0.159322439	0.466295308	0	3.598914202
Commute by Transit Density	248	0.267134853	0.379405586	0	2.41356975
Over 3 School Enrollment Density	248	1.720395477	2.124218799	0.052542312	16.95066013
College Enrollment Density	248	0.027383185	0.063985263	0.00017485	0.493986524
House Hold Density	248	2.919986923	3.184871769	0.077458383	28.10417009
Population Density	248	5.894101436	4.531475936	0.183264261	29.95086831
Median Income	248	59284.40323	33726.89862	12475	176818

Table 6 Land Use Model Descriptive Statistics

5.2 DEVELOPMENT OF CITY OF ATLANTA INTEGRATED LAND USE AND BICYCLE TRAVEL MODEL

Microsoft Excel was utilized to conduct produce a linear regression with the dependent variable frequency of bike to work by census tract representing a relative measure of strength of bicycling within each census tract for the 20 county Atlanta Metropolitan area. The explanatory variables evaluated to develop of the model are summarized in Table 6 below. The R Square values are shown to provide a comparison of the relative importance of each group of variables. Model 1 has a nominal R Square value of 0.312 compared to Model 2 which is similar to Model 1 with the exception of the Median Income variable which was excluded resulting in a slightly lower R Square value of 0.2998. The Median Income variable was not found to be significant and the value of retaining it in the model did not significantly increase explanatory power. Model 2 was used to estimate the strength of bike to work for the 20 county metro area. The explanatory variables that proved to be most significant variables in predicting the relative strength of bicycling in each census tract included: College Enrollment Density, Commute by Walking Density, Commute by Transit Density and House Hold Density. Table 6 presents the estimated results of the two models. At the Metropolitan level the strength of bicycle trips for work or school increases with college enrollment density, house hold density and commute by walking density

.

Explanatory Variables	Model 1 B	Model 2 B
Constant	0.0282*** (3.010)	0.0236*** (3.456)
Commute by Walking Density	0.0415*** (4.362)	0.0421** (4.446)*
Commute by Transit Density	0.0155 (1.205)	0.0177+ (1.421)
Over Age 3 School Enrollment Density	-0.0031 (-1.079)	-0.0030 (-1.043)
College Enrollment Density	0.2960*** (3.099)	0.2872*** (3.035)
Household Density	-0.0016* (-1.659)	-0.0016+ (-1.691)
Population Density	-0.0012 (-1.149)	-0.0012 (-1.158)
Median Income	-6.9015 E-08 (-0.720)	
Sample Size	248	248
R-square	0.3012	0.2998

Table 7 Results of Linear Regression Model

Note: Dependent Variable: Strength of Bicycling Density; T-Statistics are in Parenthesis
***Significant at 99%, ** Significant at 95%, *Significant at 90%, + Significant at 80%

5.3 HIGH PRIORITY CENSUS TRACTS WITHIN THE CITY OF ATLANTA

A land use dataset containing 1969 census tracts in the state of Georgia was developed using data from the ACS. The strength of bicycling by census tract was estimated by applying the coefficients from Model 2 independent land use variables to formulate the strength of bicycling for each census tract. The study area was then isolated to Fulton and DeKalb counties within the City of Atlanta. The significant influence of population density and college enrollment resulted in selection of census tracts proximate to colleges and universities. Census tracts near the Georgia Institute of Technology (GaTech), Spellman College, Morehouse College and Clark Atlanta University campuses as shown in Figure 21, demonstrated the highest estimated Strength of Bicycling. Figure 21 shows, census tracts, traffic signals and the arterial network in central Atlanta. Census tract (ID # 13121001202, see Figure 21) adjacent to GaTech produced an estimated strength of bicycling within the top ten statewide and was selected for additional traffic signal grouping and assessment as shown in Figure 22. Additional motivation for the selection of Census tract ID # 13121001202 was the density of bicycle facilities within the tract. Figure 23 shows the on-street bicycle facilities (1.95 miles) within the census tract under study and in nearby census tracts.

A relatively new rich set of data that captures bicycle trips via a mobile phone application was provided by the Georgia Tech Department of Civil Engineering (Watkins & LeDantec, 2015). The data is publically available and can be accessed for visualization and mapping via the Cycle Atlanta website. This data is likely to revolutionize the availability of bicycle data which traditionally has been difficult to collect. The Cycle Atlanta data shown in Figure 24 was color coded from yellow (low utilization) to red (high utilization) to compare the frequency that bicycles equipped and recording data for Cycle Atlanta are traveling routes within the study area. While rich; the distribution and use of the app is limited with the largest group of users being Georgia Tech students. The limited distribution of the app adds considerable bias to the data that must be stated prior to its interpretation. The Cycle Atlanta dataset supports visualization of all bicycle trips recorded during an analysis period that spans several months. This data and level of bicycle trips reported within the area via the Cycle Atlanta dataset. Based on the data presented in Figure 24, West Peachtree, 10th Street and 5th street are the most frequently traveled bike routes in the study area. To a great extent the data displayed in the Cycle Atlanta dataset supports the notion that comprehensive bicycle facilities increase bicycle ridership. The bicycle facilities provided on 5th Street are among the most comprehensively equipped in the City of Atlanta and include the only bicycle specific traffic signal installed in the City, see Figure 27 below.

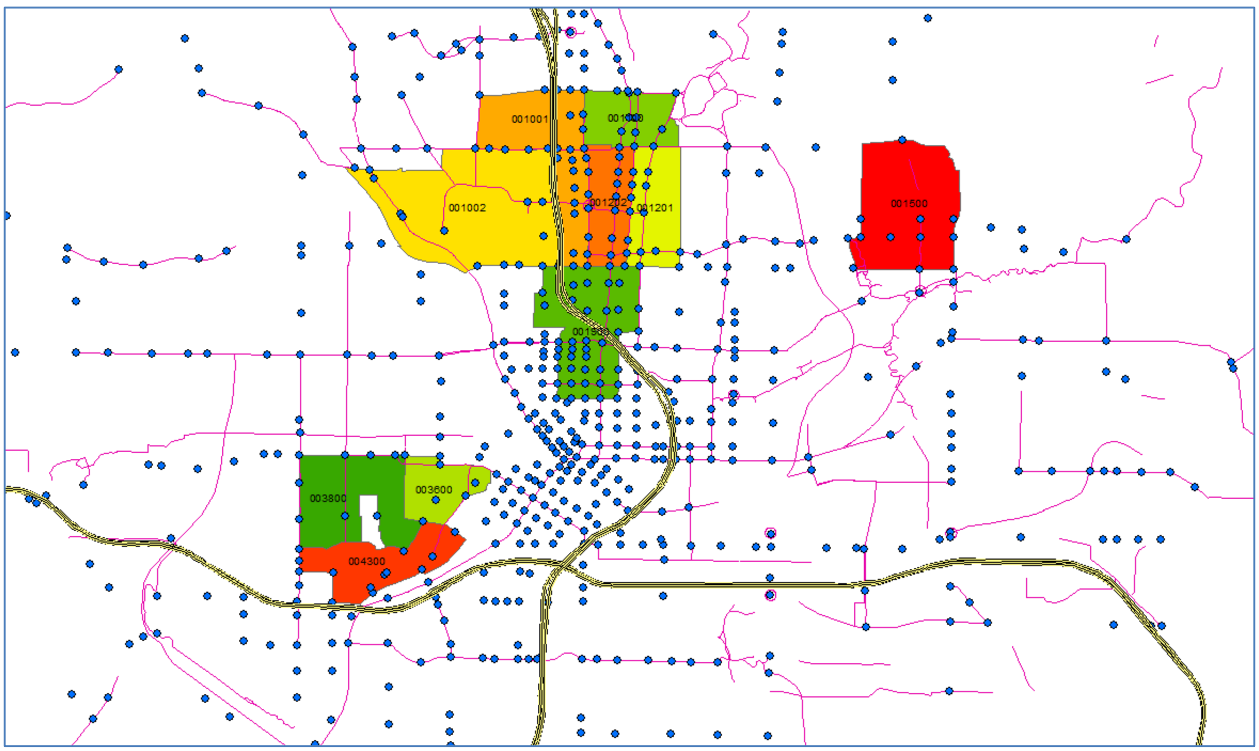

Figure 21 High Priority Census Tracts Based on Strength of Bicycling,

Figure 21shows traffic signals as dots, the bike network and census tracts that produced the top ten Strength of Bicycling Densities in the study area. Strength of Bicycling Density was estimated using the coefficients provided in Table 6, Model 2. The Cycle Atlanta data validates the model discussed in Chapter 4.1 and 5.1 as the data shown in Figure 24 and 25 demonstrates a high frequency of bicycle trips within the census tract selected for analysis. This census tract also has a relatively high density of on-street bike lanes. Figure 22 and Figure 23 highlight the study area and traffic signals on West Peachtree, Peachtree and Juniper Streets in Midtown Atlanta. Figure 23 are graphics of the on-street bicycle lanes provided within the study area, highlighted with purple lines.

Figure 22 Traffic Signal Grouping by High Priority Census Tract

Figure 23 - On-Street Bicycle Facilities Near High Priority Census Tracts

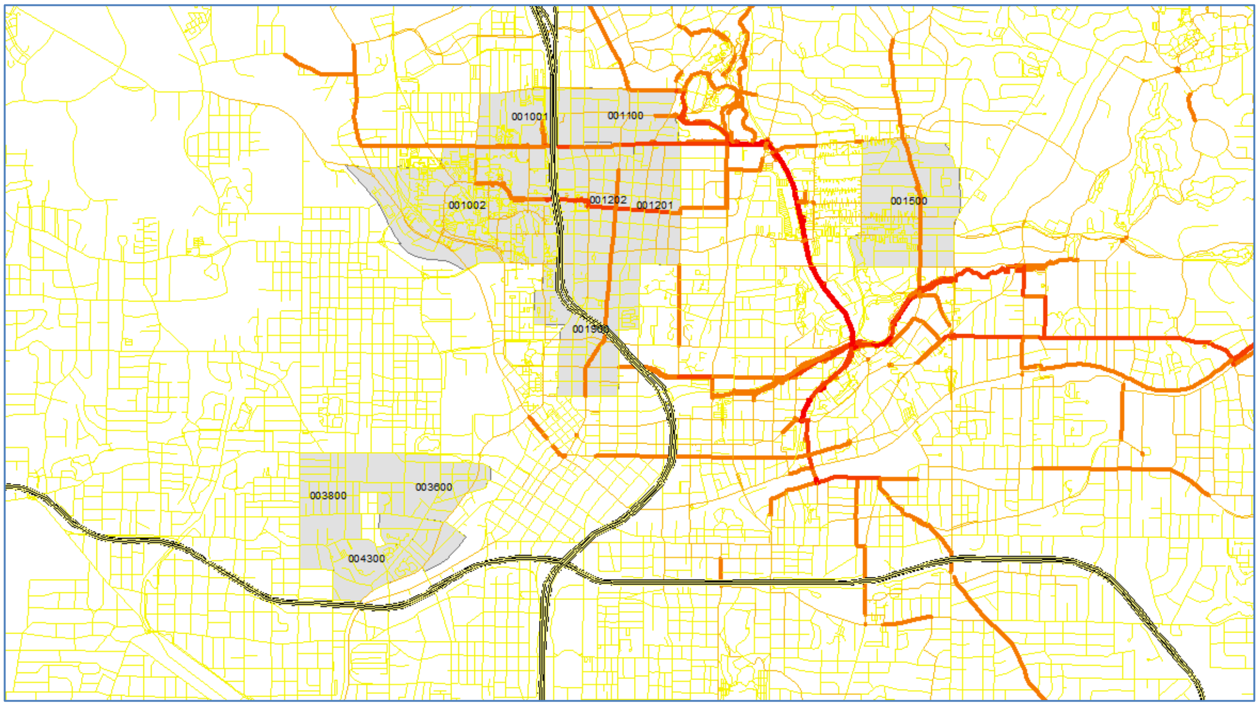

Figure 24 - Cycle Atlanta App Bike Trip Data

Figure 25 - Cycle Atlanta Bicycle Data Representing Number of Trips Recorded Near High Priority Census Tracts

5.4 ASSESSMENT OF SIGNALIZED INTERSETIONS WITHIN HIGH PRIORITY CENSUS TRACTS

Signalized intersections within Census tract ID #13121001202, as shown in Figure 21 above, were grouped to evaluate potential gaps in safety and comfort and convenience using the assessment criteria in chapter 4.2. The census tract contains 25 traffic signals and 1.95 miles of on-street bicycle lanes. Five major arterials traverse the census tract: West Peachtree Street (One-Way N/B), Juniper Street (One-Way S/B) Peachtree Street (N/B and S/B), North Avenue (E/B &

Figure 26 Bike specific traffic signal, West Peachtree and 5th St

W/B) and 10th Street (E/B & W/B). Among census tracts with the high estimated strengths of bicycling density, this census tract has the highest density of on-street bicycle lanes and is equipped with the only bicycle specific traffic signal in the City of Atlanta, located at the intersection of West Peachtree and 5th Street, as shown in Figure 27.

To complete the Tier 1 and Tier 2 assessments, described in chapter 4.2, the width of all intersection crossing, signal phasing and timing, and the presence of detection devices must be determined. A field study in addition to observation of intersections via Google earth was conducted. The City of Atlanta Office of Transportation provided signal timing for all intersections in the study area and field studies were conducted to confirm the cycle lengths and pedestrian phase settings. Detailed signal timing abstracts are available in the appendix. The signal timing abstracts include geometric details; signal timing for the AM, Mid-Day and PM peaks. Calculation of bicycle minimum green, bicycle crossing time and bicycle delay were used to complete the Tier 1 and Tier 2 assessments. Table 8 Intersection Ranking for Potential Traffic Signal Timing Operations Strategies for Bicycles below provides a ranking for the intersection grouping. The intersections in the table are in order from largest to smallest in terms of level of the potential improvement. In Table 8 below, Column 3, Sum of Tier 1 and Tier 2 Rating for all intersection Approaches, provides the relative potential improvement in safety, comfort and convenience as an outcome of the assessment. The level of potential improvement increases with the sum of the Tier 1 and Tier 2 assessment. Chapter 3 provides TSOSB that could be implemented in response to the gaps in bicycle safety comfort and convenience that have been identified. Table 9, 10 and 11 provide the details of the Tier 1and Tier 2 assessment.

The Tier 3 assessment involves a review of the City of Atlanta Bicycle Master Plan to determine policies, goals or objectives that might articulate a desire for bicycle mode preference. The Atlanta Region Bicycle Transportation and Pedestrian Walkways Plan, developed in 2007 provide several goals that establish the need to improve bicycle infrastructure. The objectives stated in the plan are oriented around improving the Level of Service of bicycle facilities but do not clearly license bicycle mode priority. At this time no Tier 3 bicycle mode preference strategies are recommended for implementation.

Table 8 Intersection Ranking for Potential Traffic Signal Timing Operations Strategies for Bicycles

Rank	Intersection	Sum of Tier 1 and Tier 2 Rating for all intersection Approaches
1	Peachtree & 10 St	49
2	Peachtree St & 5th St	46
3	Juniper St & 10 St	42
4	Juniper St & 5th St	41
5	West Peachtree & 5th St	35
6	Peachtree St & Ponce De Leon Ave	34
7	West Peachtree & Ponce De Leon Ave	22
8	West Peachtree & 10 St	21
9	Juniper St & Ponce De Leon Ave	19
10	West Peachtree & West Peachtree Place	18
11	West Peachtree & 8th St	14
12	Peachtree St & North Ave	14
13	Peachtree St & Peachtree St Place	10
14	Peachtree St & 8th St	10
15	Peachtree St & 7th St	10
16	Peachtree St & 6th St	10
17	Peachtree St & 3rd St	10
18	Juniper St & 7th St	8
19	West Peachtree & North Ave	7
20	Juniper St & 8th St	7
21	West Peachtree & 6th St	6
22	West Peachtree & 3rd St	5
23	Juniper St & 6th St	5
24	Juniper St & 3rd St	0
25	Juniper St & North Ave	0

Intersection	Tier 1 - Safety Assessment															Tier 2 - Comfort & Convenience Assessmen					Rating
	Minimum Green					Bicycle Crossing Time					Detection					Delay					
West Peachtree & 10 St	N/B	E/B	S/B	W/B	Total	N/B	E/B	S/B	W/B	Total	N/B	E/B	S/B	W/B	Total	N/B	E/B	S/B	W/B	Total	
	E	E	NBR	E	0	B	B	NBR	B	15	F	F	NBR	F	0	46	5	NBR	33	6	21
	0	0	0	0		5	5	0	5		0	0	0	0		3	0	0	3		
West Peachtree & West Peachtree Place	N/B	E/B	S/B	W/B	Total	N/B	E/B	S/B	W/B	Total	N/B	E/B	S/B	W/B	Total	N/B	E/B	S/B	W/B	Total	
	E	NBR	NBR	NBR	0	B	NBR	E	NBR	15	F	NBR	F	NBR	0	15	NBR	NBR	19	3	18
	0	0	0	0		5	5	0	5		0	0	0	0		1	1	0	1		
West Peachtree & 8th St	N/B	E/B	S/B	W/B	Total	N/B	E/B	S/B	W/B	Total	N/B	E/B	S/B	W/B	Total	N/B	E/B	S/B	W/B	Total	
	E	NBR	NBR	NBR	0	B	NBR	B	NBR	10	F	NBR	F	NBR	0	9	26	NBR	26	4	14
	0	0	0	0		5	0	5	0		0	0	0	0		0	2	0	2		
West Peachtree & 6th St	N/B	E/B	S/B	W/B	Total	N/B	E/B	S/B	W/B	Total	N/B	E/B	S/B	W/B	Total	N/B	E/B	S/B	W/B	Total	
	E	NBR	NBR	NBR	0	B	NBR	NBR	NBR	5	F	NBR	NBR	NBR	0	12	NBR	NBR	NBR	1	6
	0	0	0	0		5	0	0	0		0	0	0	0		1	0	0	0		
West Peachtree & 5th St	N/B	E/B	S/B	W/B	Total	N/B	E/B	S/B	W/B	Total	N/B	E/B	S/B	W/B	Total	N/B	E/B	S/B	W/B	Total	
	E	E	NBR	E	0	B	B	NBR	B	15	F	p	NBR	p	10	9	51	NBR	35	10	35
	0	0	0	0		5	5	0	5		0	5	0	5		0	5	0	5		
West Peachtree & 3rd St	N/B	E/B	S/B	W/B	Total	N/B	E/B	S/B	W/B	Total	N/B	E/B	S/B	W/B	Total	N/B	E/B	S/B	W/B	Total	
	E	NBR	NBR	NBR	0	B	NBR	NBR	NBR	5	F	NBR	NBR	NBR	0	8	NBR	NBR	NBR	0	5
	0	0	0	0		5	0	0	0		0	0	0	0		0	0	0	0		
West Peachtree & Ponce De Leon Ave	N/B	E/B	S/B	W/B	Total	N/B	E/B	S/B	W/B	Total	N/B	E/B	S/B	W/B	Total	N/B	E/B	S/B	W/B	Total	
	E	NBR	NBR	E	0	B	NBR	NBR	B	10	F	NBR	NBR	A	10	14	NBR	NBR	19	2	22
	0	0	0	0		5	0	0	5		0	0	0	10		1	0	0	1		
West Peachtree & North Ave	N/B	E/B	S/B	W/B	Total	N/B	E/B	S/B	W/B	Total	N/B	E/B	S/B	W/B	Total	N/B	E/B	S/B	W/B	Total	
	E	NBR	NBR	NBR	0	B	NBR	NBR	NBR	5	F	NBR	NBR	NBR	0	25	NBR	NBR	NBR	2	7
	0	0	0	0		5	0	0	0		0	0	0	0		2	0	0	0		

Table 9 West Peachtree Street Tier 1 & Tier 2 Assessment Summary

Intersection	Tier 1 - Safety Assessment															Tier 2 - Comfort & Convenience Assessment					Rating
	Minimum Green					Bicycle Crossing Time					Detection					Delay					
Peachtree & 10 St	N/B	E/B	S/B	W/B	Total	N/B	E/B	S/B	W/B	Total	N/B	E/B	S/B	W/B	Total	N/B	E/B	S/B	W/B	Total	49
	E	E	E	E	0	B	B	B	B	20	F	A	F	A	20	24	27	24	31	9	
	0	0	0	0		5	5	5	5		0	10	0	10		2	2	2	3		
Peachtree St & Peachtree St Place	N/B	E/B	S/B	W/B	Total	N/B	E/B	S/B	W/B	Total	N/B	E/B	S/B	W/B	Total	N/B	E/B	S/B	W/B	Total	10
	E	NBR	E	NBR	0	B	NBR	B	NBR	10	F	NBR	F	NBR	0	10	NBR	10	NBR	0	
	0	0	0	0		5	0	5	0		0	0	0	0		0	0	0	0		
Peachtree St & 8th St	N/B	E/B	S/B	W/B	Total	N/B	E/B	S/B	W/B	Total	N/B	E/B	S/B	W/B	Total	N/B	E/B	S/B	W/B	Total	10
	E	NBR	E	NBR	0	B	NBR	B	NBR	10	F	NBR	F	NBR	0	10	NBR	10	NBR	0	
	0	0	0	0		5	0	5	0		0	0	0	0		0	0	0	0		
Peachtree St & 7th St	N/B	E/B	S/B	W/B	Total	N/B	E/B	S/B	W/B	Total	N/B	E/B	S/B	W/B	Total	N/B	E/B	S/B	W/B	Total	10
	E	NBR	E	NBR	0	B	NBR	B	NBR	10	F	NBR	F	NBR	0	10	NBR	10	NBR	0	
	0	0	0	0		5	0	5	0		0	0	0	0		0	0	0	0		
Peachtree St & 6th St	N/B	E/B	S/B	W/B	Total	N/B	E/B	S/B	W/B	Total	N/B	E/B	S/B	W/B	Total	N/B	E/B	S/B	W/B	Total	10
	E	NBR	E	NBR	0	B	NBR	B	NBR	10	F	NBR	F	NBR	0	7	NBR	7	NBR	0	
	0	0	0	0		5	0	5	0		0	0	0	0		0	0	0	0		
Peachtree St & 5th St	N/B	E/B	S/B	W/B	Total	N/B	E/B	S/B	W/B	Total	N/B	E/B	S/B	W/B	Total	N/B	E/B	S/B	W/B	Total	46
	E	E	E	E	0	B	B	B	B	20	F	A	F	A	20	12	22	12	22	6	
	0	0	0	0		5	5	5	5		0	10	0	10		1	2	1	2		
Peachtree St & 3rd St	N/B	E/B	S/B	W/B	Total	N/B	E/B	S/B	W/B	Total	N/B	E/B	S/B	W/B	Total	N/B	E/B	S/B	W/B	Total	10
	E	NBR	E	NBR	0	B	NBR	B	NBR	10	F	NBR	F	NBR	0	6	NBR	6	NBR	0	
	0	0	0	0		5	0	5	0		0	0	0	0		0	0	0	0		
Peachtree St & Ponce De Leon Ave	N/B	E/B	S/B	W/B	Total	N/B	E/B	S/B	W/B	Total	N/B	E/B	S/B	W/B	Total	N/B	E/B	S/B	W/B	Total	34
	E	B	E	B	10	B	B	B	B	20	F	F	F	F	0	10	26	10	26	4	
	0	5	0	5		5	5	5	5		0	0	0	0		0	2	0	2		
Peachtree St & North Ave	N/B	E/B	S/B	W/B	Total	N/B	E/B	S/B	W/B	Total	N/B	E/B	S/B	W/B	Total	N/B	E/B	S/B	W/B	Total	14
	E	NBR	E	NBR	0	B	NBR	B	NBR	10	F	NBR	F	NBR	0	23	NBR	23	NBR	4	
	0	0	0	0		5	0	5	0		0	0	0	0		2	0	2	0		

Table 10 - Peachtree Street Tier 1 & Tier 2 Assessment Summary

Intersection	Tier 1 - Safety Assessment															Tier 2 - Comfort & Convenience Assessment					Rating
	Minimum Green					**Bicycle Crossing Time**					**Detection**					**Delay**					
Juniper St & 10 St	N/B	E/B	S/B	W/B	Total	N/B	E/B	S/B	W/B	Total	N/B	E/B	S/B	W/B	Total	N/B	E/B	S/B	W/B	Total	42
	E	E	E	E	0	NBR	B	B	B	15	NBR	A	F	A	20	22	22	22	12	7	
	0	0	0	0		0	5	5	5		0	10	0	10		2	2	2	1		
Juniper St & 8th St	N/B	E/B	S/B	W/B	Total	N/B	E/B	S/B	W/B	Total	N/B	E/B	S/B	W/B	Total	N/B	E/B	S/B	W/B	Total	7
	NBR	NBR	E	NBR	0	NBR	NBR	B	NBR	5	NBR	NBR	F	NBR	0	11	NBR	11	NBR	2	
	0	0	0	0		0	0	5	0		0	0	0	0		1	0	1	0		
Juniper St & 7th St	N/B	E/B	S/B	W/B	Total	N/B	E/B	S/B	W/B	Total	N/B	E/B	S/B	W/B	Total	N/B	E/B	S/B	W/B	Total	8
	NBR	NBR	E	NBR	0	NBR	NBR	B	NBR	5	NBR	NBR	F	NBR	0	12	NBR	12	NBR	3	
	0	0	0	0		0	0	5	0		0	0	0	0		1	0	1	1		
Juniper St & 6th St	N/B	E/B	S/B	W/B	Total	N/B	E/B	S/B	W/B	Total	N/B	E/B	S/B	W/B	Total	N/B	E/B	S/B	W/B	Total	5
	NBR	NBR	E	NBR	0	NBR	NBR	B	NBR	5	NBR	NBR	F	NBR	0	NBR	NBR	3	NBR	0	
	0	0	0	0		0	0	5	0		0	0	0	0		0	0	0	0		
Juniper St & 5th St	N/B	E/B	S/B	W/B	Total	N/B	E/B	S/B	W/B	Total	N/B	E/B	S/B	W/B	Total	N/B	E/B	S/B	W/B	Total	41
	NBR	NBR	E	NBR	0	NBR	B	B	B	15	F	A	F	A	20	11	23	11	23	6	
	0	0	0	0		0	5	5	5		0	10	0	10		1	2	1	2		
Juniper St & 3rd St	N/B	E/B	S/B	W/B	Total	N/B	E/B	S/B	W/B	Total	N/B	E/B	S/B	W/B	Total	N/B	E/B	S/B	W/B	Total	0
	NBR	NBR	E	NBR	0	NBR	NBR	E	NBR	0	F	NBR	F	NBR	0	8	NBR	8	NBR	0	
	0	0	0	0		0	0	0	0		0	0	0	0		0	0	0	0		
Juniper St & Ponce De Leon Ave	N/B	E/B	S/B	W/B	Total	N/B	E/B	S/B	W/B	Total	N/B	E/B	S/B	W/B	Total	N/B	E/B	S/B	W/B	Total	19
	NBR	E	E	E	0	NBR	B	B	B	15	NBR	F	F	F	0	NBR	27	9	27	4	
	0	0	0	0		0	5	5	5		0	0	0	0		0	2	0	2		
Juniper St & North Ave	N/B	E/B	S/B	W/B	Total	N/B	E/B	S/B	W/B	Total	N/B	E/B	S/B	W/B	Total	N/B	E/B	S/B	W/B	Total	0
	NBR	NBR	NBR	NBR	0	NBR	NBR	NBR	NBR	0	NBR	NBR	NBR	NBR	0	NBR	NBR	NBR	NBR	0	
	0	0	0	0		0	0	0	0		0	0	0	0		0	0	0	0		

Table 11 Juniper Street Tier 1 & Tier 2 Assessment Summary

6 CONCLUSION

Bicycling is an active travel mode that addresses health risks associated with obesity and a number of environmental and social impacts imposed by decades of low cost, convenient, and efficient automobile travel. An initial surge of bicycle infrastructure implementation began nearly two decades ago and primarily utilized an Infrastructure Based Approach that has led to large networks of discontinuous on-street bicycle lanes. Ongoing research has classified different types of bicycle riders and identified the need to address the Level of Traffic Stress experienced by bicycle riders to promote higher levels of bicycle ridership. The inertia at federal, state, and local levels to expand bicycle networks is increasing and both policies and a larger share of transportation funding are promoting enhancements to improve bicycle facilities.

Very few studies have been completed to definitively demonstrate the impact of individual design or operations strategies for bicycles. Cross-sectional studies that compare bicycle ridership across multiple jurisdictions suggests that provision of comprehensive bicycle facilities results in higher levels of bicycle ridership. Traffic Signal Operational Strategies for Bicycles (TSOSB) may improve the safety, comfort and convenience of bicycle facilities by improving the continuity of on-street bicycle networks. Infrastructure based strategies to guide the implementation of bicycle infrastructure while cost effective, may not result in desired increases in bicycle ridership. Demand based approaches that evaluate land use characteristic and strategically prioritize implementation are much more likely to produce increases in bicycle ridership.

The Demand Based Approach presented in this research employed an integrated land use and travel demand dataset to model the strength of bicycling by census tracts. The fact that the model identified census tracts within the City of Atlanta with high densities of existing on-street bicycle facilities validates the utility of the Demand Based Approach. The grouping and analysis of signalized intersections using the three assessment tiers provides a systematic approach to prioritize and implement TSOSB. Many of the strategies identified in Chapter 3 can be implemented at a very low costs and intuitively address the barrier of complex intersections.

6.1 RESEARCH NEEDS

One potential reason for the significant gap between the implementation of on-street bicycle facilities and the supplemental implementation of TSOSB is the lack of compelling research on the impacts of the strategies. An independent analysis of each TSOSB should be conducted to adequately quantify the impacts on safety, comfort and convenience; intersection efficiency and bicycle ridership. The process used to weight and score each Tier assessment was developed primarily to prioritize safety and to penalize intersection operations that create excessive delay for bicycles. The scores assigned to intersection approaches did not consider different gradations of deficiency. Intersection that for instance failed to meet minimum green requirements for bicycle by 0.1 second could be ranked similarly to intersections that require 3 or more seconds of additional minimum green.

The purpose of the Demand Based Approach was to support alignment of bicycle facility improvements with zones where the greatest latent potential for bicycle trips exists. The Cycle Atlanta bicycle dataset offers a rich source of information that could directly identify the most heavily traveled bicycle routes. To successfully utilize the probe based data collected by resources like Cycle Atlanta a representative sample of bicyclist that regularly utilize the application throughout the entire jurisdiction would need to be established to mitigate bias.

The Level of Traffic Stress (LTS) Research evaluated intersection approaches but did not classify traffic signal operational characteristics in terms of LTS. The addition of signalized intersection operational characteristics to the LTS analysis could do much to promote the implementation of TSOSB. The responses to the targeted survey of agencies with significant on-street bicycle networks frequently demonstrated awareness of, but a lack of implementation of a number of TSOSB. Improving the recognition of TSOSB to address LTS and improve both perceived and actual levels of safety, comfort and convenience is key to elevating the need for and benefit of these strategies.

The Demand Based Approach described in this research identified land use variables that contribute to bicycle ridership. These variables were then used to identify critical zones that were ripe for TSOSB. TSOSB are a low cost investment opportunity to improve the safety, comfort and convenience of the bicycle network by directly addressing operations objectives that are oriented towards the bike mode. NHSTA reported that 30% of all bicycle fatalities occur at intersections and significant research documents bicyclist persistent violation of traffic signal indications. Applying the Demand Based Approach described in this research to implement TSOSB within existing on-street bicycle networks offers a systematic process to improve safety, comfort and convenience to provide more comprehensive bicycle facilities.

APPENDIX A: TARGETED AGENCY SURVEY QUESTIONS

Targeted Agency Survey

The intent of the target agency survey is to gain insight into innovative practices that are currently in use to enhance bicycle quality of service, comfort, safety and convenience and methods that are in use to locate and prioritize their implementation. Depending on the size of the agency, the responsibility for planning, design and implementation of bicycle facilities and signalized intersections could reside within a single individual or potentially within two or more divisions within a single or multiple organization(s). The literature review provides data about signal timing strategies and methodology for locating and prioritizing its implementation. What follows is a list of objectives for the interviews and the basis for selecting the interview candidates.

Interview Objectives

- Identify signalized intersection operations strategies that are currently in use to enhance bicycle quality of service, comfort, safety and convenience.
- Identify Signalized intersection design guidelines and infrastructure needs to support implementation of signalized intersection operational strategies for bicycles.
- Identify criteria in use to identify the need for specific signalized intersection operational strategies for bicycles.

- Identify methodology to locate and prioritize the implementation of bicycle infrastructure in general and specifically for signalized intersections.

Targeted Survey Introduction

The following interview questions are part of a Georgia Institute of Technology Graduate Thesis, examining methods to identify and prioritize the need for signalized intersection operational strategies for bicycles. National best practice encourages alignment planned bicycle infrastructure with other projects such as repaving to minimize implementation costs. While cost effective, this implementation method tends to create discontinuous bicycle networks during implementation over a number of years and frequently bypasses potential bicycle improvements at signalized intersections. As the bicycle network expands and becomes more complete within a region, the lack of signalized intersection operational improvements tends to persists and may deter the use of the bicycle mode.

A review of available literature has identified a number of jurisdictions with extensive on-street bicycle lanes; increasing the potential for implementation of signalized intersection operational strategies. The questions that follow are intended to validate the use or consideration of signalized operational strategies that have been documented in research, design guides or as agency standards as well as methods currently in use to prioritize implementation of bicycle infrastructure.

Date ___________________

Name ____

Agency____

Job Title ____

Primary Job Function ____

Signalized Intersection Operational Strategies for Bicycles

About you

1 / 5 — 20%

***1. Contact Information**

Name ____________________

Agency / Organization ____________________

***2. Describe the size of the traffic signal network in your jurisdiction?**

- ○ Small (50 or fewer traffic signals)
- ○ Medium (51 - 200 traffic signals)
- ○ Large (201 - 400 traffic signals)
- ○ Very Large (greater than 400)

***3. What percentage of your job function is related to the planning, design or implementation of:**

	0	1% - 24%	25% - 50%	51% - 75%	75% <
Bicycle Facilities	○	○	○	○	○
Traffic Signals	○	○	○	○	○

Other (please specify)

____

***4. What percentage of the traffic signals located along designated bicycle routes in your jurisdiction are routinely (at least once every 24 months) evaluated for safety, quality of service, comfort, or convenience for the bicycle mode?**

- ○ 0%
- ○ 1% - 20%
- ○ 21% - 40%
- ○ 41% - 60%
- ○ 60% <

***5. The list below identifies signalized intersection operational strategies for bicycles currently in use domestically or internationally. For each strategy rate your agency's level of consideration:**

	Not aware of the strategy	Aware of the strategy, but not proposed	Strategy proposed, but rejected	Strategy proposed, but not in use	Strategy proposed, implementation pending	Strategy currently in use
Bicycle detection to call traffic signal phase(s). (Includes, push buttons accessible from bicycle lanes/paths etc., Inductive Loops, video detection, microwave, etc...)	○	○	○	○	○	○
Bicycle minimum green time	○	○	○	○	○	○
Bicycle passage time or extension. (Use of bicycle detection and traffic signal controller settings to extend phases specifically for bicycles)	○	○	○	○	○	○
Leading Bicycle Interval	○	○	○	○	○	○
Short Cycle Lengths to minimize bicycle delay	○	○	○	○	○	○
Actuated coordinated operation. (Controller feature to reduce the time used by coordinated phase)	○	○	○	○	○	○
Bicycle progression or bicycle green wave	○	○	○	○	○	○
Exclusive bicycle phases - with bicycle specific traffic signals	○	○	○	○	○	○
Change (Yellow) and Clearance intervals (All-Red) to accommodate bicycles	○	○	○	○	○	○

***6. Please identify any of the following documents currently utilized by your agency to guide the design or operation of signalized intersection operations strategies for bicycles. (Select all that apply)**

- ☐ MUTCD-FHWA
- ☐ MUTCD-CA
- ☐ AASHTO Guide for the Development of Bicycle Facilities
- ☐ National Association of City Transportation Officials (NACTO) Design Guide
- ☐ Agency has developed its own bicycle design guide or standard plans
- ☐ Conference Proceedings (i.e. TRB, ITE, ASCE)
- ☐ None of the Above
- ☐ Other (please specify)

***7. Rate the relevance of the following criteria as indicators of the need for signalized intersection operational improvements to accommodate bicycles.**

	Not considered	Low relevance	Moderate relevance	High relevance
Safety analysis	○	○	○	○
Surveys of bicycle users	○	○	○	○
General travel surveys	○	○	○	○
Complaints	○	○	○	○
Community or focus groups	○	○	○	○
Quality of Service Analysis (Highway Capacity Manual)	○	○	○	○

Other (please specify)

***8. Please rate the relevance of the following criteria are in determining the location of on-street bicycle facilities in general?**

	Not considered	Low relevance	Moderate relevance	High relevance
Suitability of routes to accommodate bicycles (e.g. lane width, pavement conditions, traffic volume)	○	○	○	○
Land use characteristics (e.g. population density, retail density)	○	○	○	○
Bicycle Ridership estimates for recreational use	○	○	○	○
Bicycle Ridership estimates for utilitarian use	○	○	○	○
Directness of route (e.g. connectivity of a route between trip generators and attractors)	○	○	○	○
Demographics (e.g. Income, vehicle ownership, age)	○	○	○	○
Bicycle revealed demand (e.g. Bicycle volume counts)	○	○	○	○

Other (please specify)

***9. Please rate the potential impact of the following strategies to increase bicycle ridership?**

	Not considered	Low impact	Moderate impact	high impact
Integration of transit and bicycle infrastructure	○	○	○	○
Bicycle parking at work sites	○	○	○	○
Bicycle Detection at signalized intersections	○	○	○	○
Colored (e.g. green or other pigment) bicycle lanes	○	○	○	○
Bicycle boxes	○	○	○	○
Education and Training	○	○	○	○

Other (please specify)

10. Do you have any other comments you would like to share on the topic?

APPENDIX B: PRIORITY ZONE SIGNAL TIMING

Intersection: **North Ave & West Peachtree**

Wcd N/S (ft)	Wcd E/W (ft)	N/S Speed Limit	E/W Speed Limit	N/S Vehicle Change Period (s)	E/W Vehicle Change Period (s)	N/S Bicycle Minimum Green (s)	E/W Bicycle Minimum Green (s)	N/S BMG Rating	E/W BMG Rating	N/S Bicycle Crossing Time (s)	E/W Bicycle Crossing Time (s)	N/S BCT Assessment	E/W BCT Assessment	Controller BMG Capability	Fixed Time (FT) or Actuated (ACT)
110	90	30	30	6	6	8	7	1	1	10.4	9.0	-1	-1		ACT
										5.3	5.9				

PM — **W Peachtree St** / **North Ave**

	Phase 2: W/S Ped & N/B Thru				Bike Delay	Phase 3: E/B LT				Phase 4: W/B Ped & Thur				Bike Delay
	Walk	FDW	Yellow	All-Red	25			Yellow	All-Red	Walk	FDW	Yellow	All-Red	24
	7	21	3.0	2.3				3.0	2.8	7	21	4.0	1.9	
		Min Green			Bike Facility Type		Min Green				Min Green			Bike Facility Type
		15					5				9			
Cycle	39.7				B - Lane	22.2				41.1				Sharrow
120	45					28				47				

	Phase 6: E/S Ped & N/B Thru						Phase 8: E/B Ped & Thru				Bike Delay
	Walk	FDW	Yellow	All-Red			Walk	FDW	Yellow	All-Red	10
	7	23	3.0	2.3			7	23	4.0	1.9	
		Min Green			Bike Facility Type			Min Green			Bike Facility Type
		15						9			
Cycle	39.7				B - Lane		69.1				Sharrow
120	45						75				

Intersection: **Peachtree Place & West Peachtree**

Wcd N/S (ft)	Wcd E/W (ft)	N/S Speed Limit	E/W Speed Limit	N/S Vehicle Change Period (s)	E/W Vehicle Change Period (s)	N/S Bicycle Minimum Green (s)	E/W Bicycle Minimum Green (s)	N/S BMG Rating	E/W BMG Rating	N/S Bicycle Crossing Time (s)	E/W Bicycle Crossing Time (s)	N/S BCT Assessment	E/W BCT Assessment	Controller BMG Capability	Fixed Time (FT) or Actuated (ACT)
70	80	30	25	5	6	6	6	1	1	7.6	8.3	-1	-1		ACT
										4.9	5.9				

PM — **W Peachtree St** — **Peachtree Place**

	Phase 2					Phase 4				
	W/S Ped & N/B Thru				**Bike Delay**					**Bike Delay**
	Walk	FDW	Yellow	All-Red		Walk	FDW	Yellow	All-Red	
	7	21			**15**	7	21			**19**
		Min Green					Min Green			
		15	3.1	1.8	Bike Facility Type		15	3.0	2.9	Bike Facility Type
Cycle	58.1				B - Lane	51.1				Sharrow
120	63					57				

	Phase 6					Phase 8				
	E/S Ped & N/B Thru					E/B Ped & Thru				**Bike Delay**
	Walk	FDW	Yellow	All-Red		Walk	FDW	Yellow	All-Red	
	7	23				7	23			**19**
		Min Green					Min Green			
		15	3.1	1.8	Bike Facility Type		15	3.0	2.9	Bike Facility Type
Cycle	58.1				B - Lane	51.1				Sharrow
120	63					57				

Intersection: **8th St & West Peachtree**

Wcd N/S (ft)	Wcd E/W (ft)	N/S Speed Limit	E/W Speed Limit	N/S Vehicle Change Period (s)	E/W Vehicle Change Period (s)	N/S Bicycle Minimum Green (s)	E/W Bicycle Minimum Green (s)	N/S BMG Rating	E/W BMG Rating	N/S Bicycle Crossing Time (s)	E/W Bicycle Crossing Time (s)	N/S BCT Assessment	E/W BCT Assessment	Controller BMG Capability	Fixed Time (FT) or Actuated (ACT)
40	60	30	25	5	5	4	5	1	1	5.6	7.0	-1	-1		Fixed
										5.0	5.6				

PM — **W Peachtree St** / **8th St**

	Phase 2				Bike Delay	Phase 4				Bike Delay
	W/S Ped & N/B Thru				9					26
	Walk	FDW	Yellow	All-Red		Walk	FDW	Yellow	All-Red	
	7	21	3.1	1.8		7	21	3.0	2.9	
		Min Green 15			Bike Facility Type		Min Green 15			Bike Facility Type
Cycle	70.1				B - Lane	39.1				-
120	75					45				

	Phase 6					Phase 8				Bike Delay
	E/S Ped & N/B Thru					E/B Ped & Thru				26
	Walk	FDW	Yellow	All-Red		Walk	FDW	Yellow	All-Red	
	7	23	3.1	1.8		7	23	3.0	2.9	
		Min Green 15			Bike Facility Type		Min Green 15			Bike Facility Type
Cycle	70.1				B - Lane	39.1				-
120	75					45				

Intersection: **6th St / Biltmore & West Peachtree**

Wcd N/S (ft)	Wcd E/W (ft)	N/S Speed Limit	E/W Speed Limit	N/S Vehicle Change Period (s)	E/W Vehicle Change Period (s)	N/S Bicycle Minimum Green (s)	E/W Bicycle Minimum Green (s)	N/S BMG Rating	E/W BMG Rating	N/S Bicycle Crossing Time (s)	E/W Bicycle Crossing Time (s)	N/S BCT Assessment	E/W BCT Assessment	Controller BMG Capability	Fixed Time (FT) or Actuated (ACT)
60	81	30	25	5	6	5	6	1	1	7.0	8.4	-1	-1		Fixed
										5.2	5.6				

PM — **W Peachtree St** / **6th St / Biltmore**

	Phase 2				Bike Delay	Phase 4				Bike Delay
	W/S Ped & N/B Thru				12					21
	Walk	FDW	Yellow	All-Red		Walk	FDW	Yellow	All-Red	
	7	21	3.1	1.8		7	21	3.0	2.9	
		Min Green 15			Bike Facility Type		Min Green 15			Bike Facility Type
Cycle	63.1				B - Lane	46.1				Sharrow
120	68					52				

	Phase 6					Phase 8				Bike Delay
	E/S Ped & N/B Thru					E/B Ped & Thru				21
	Walk	FDW	Yellow	All-Red		Walk	FDW	Yellow	All-Red	
	7	23	3.1	1.8		7	23	3.0	2.9	
		Min Green 15			Bike Facility Type		Min Green 15			Bike Facility Type
Cycle	63.1				B - Lane	46.1				Sharrow
120	68					52				

Intersection: **5th St & West Peachtree**

Wcd N/S (ft)	Wcd E/W (ft)	N/S Speed Limit	E/W Speed Limit	N/S Vehicle Change Period (s)	E/W Vehicle Change Period (s)	N/S Bicycle Minimum Green (s)	E/W Bicycle Minimum Green (s)	N/S BMG Rating	E/W BMG Rating	N/S Bicycle Crossing Time (s)	E/W Bicycle Crossing Time (s)	N/S BCT Assessment	E/W BCT Assessment	Controller BMG Capability	Fixed Time (FT) or Actuated (ACT)
58	71	30	25	5	5	5	6	1	1	6.8	7.7	-1	-1		ACT
										5.1	5.6				

W Peachtree St — **5th St**

AM

Phase 2

W/S Ped & N/B Thru				Bike Delay	E/W - Bike Lane				Bike Delay
Walk	FDW	Yellow	All-Red		Walk	FDW	Yellow	All-Red	
0	0	3.1	2.0	9	0	0	3.1	2.0	51
	Min Green 15			Bike Facility Type		Min Green 1			
70.9				B - Lane	6.9				
76					12				

Cycle: 120

Phase 4

E/B Ped & Thru				Bike Delay
Walk	FDW	Yellow	All-Red	
7	11	3.0	2.6	35
	Min Green 18			Bike Facility Type
26.4				Sharrow
32				

Phase 6

E/S Ped & N/B Thru					E/W - Bike Lane			
Walk	FDW	Yellow	All-Red		Walk	FDW	Yellow	All-Red
7	10	3.1	2.0		7	10	3.0	2.6
	Min Green 15			Bike Facility Type		Min Green 10		
59.9				B - Lane	49.4			
65					55			

Cycle: 120

Phase 8

Bike Delay
Bike Facility Type
Sharrow

Phase 2

W/S Ped & N/B Thru			
Walk	FDW	Yellow	All-Red
0	0	3.0	1.0
	Min Green 1		
7.0			
11			

Intersection: **3rd St & West Peachtree**

Wcd N/S (ft)	Wcd E/W (ft)	N/S Speed Limit	E/W Speed Limit	N/S Vehicle Change Period (s)	E/W Vehicle Change Period (s)	N/S Bicycle Minimum Green (s)	E/W Bicycle Minimum Green (s)	N/S BMG Rating	E/W BMG Rating	N/S Bicycle Crossing Time (s)	E/W Bicycle Crossing Time (s)	N/S BCT Assessment	E/W BCT Assessment	Controller BMG Capability	Fixed Time (FT) or Actuated (ACT)
81	90	30	25	5	6	7	7	1	1	8.4	9.0	-1	-1		ACT
										4.9	5.9				

PM — **W Peachtree St** / **3rd St**

Phase 2 — W/S Ped & N/B Thru

Walk	FDW	Min Green	Yellow	All-Red	Bike Delay	Bike Facility Type
7	10	15	3.4	1.5	8	B - Lane

74.1	79

Phase 4

Walk	FDW	Min Green	Yellow	All-Red	Bike Delay	Bike Facility Type
7	12	20	3.2	2.7	28	-

35.1	41

Cycle: 120

Phase 6 — E/S Ped & N/B Thru

Walk	FDW	Min Green	Yellow	All-Red	Bike Facility Type
7	10	15	3.4	1.8	B - Lane

73.8	79

Phase 8 — E/B Ped & Thru

Walk	FDW	Min Green	Yellow	All-Red	Bike Delay	Bike Facility Type
7	12	20	3.2	2.7	28	-

35.1	41

Cycle: 120

Intersection: **Ponce De Leon Ave & West Peachtree**

Wcd N/S (ft)	Wcd E/W (ft)	N/S Speed Limit	E/W Speed Limit	N/S Vehicle Change Period (s)	E/W Vehicle Change Period (s)	N/S Bicycle Minimum Green (s)	E/W Bicycle Minimum Green (s)	N/S BMG Rating	E/W BMG Rating	N/S Bicycle Crossing Time (s)	E/W Bicycle Crossing Time (s)	N/S BCT Assessment	E/W BCT Assessment	Controller BMG Capability	Fixed Time (FT) or Actuated (ACT)
79	77	30	25	5	5	6	6	1	1	8.3	8.1	-1	-1		ACT
										5.2	5.9				

PM — **W Peachtree St** / **Ponce De Leon Ave**

Phase 2 — W/S Ped & N/B Thru

Walk	FDW	Min Green	Yellow	All-Red	Bike Delay	Bike Facility Type
7	10	15	3.3	1.9	14	B - Lane

59.8	65

Phase 4

Walk	FDW	Min Green	Yellow	All-Red	Bike Delay	Bike Facility Type
7	12	15	4.2	1.7	19	Sharrow

49.1	55

Cycle: 120

Phase 6 — E/S Ped & N/B Thru

Walk	FDW	Min Green	Yellow	All-Red	Bike Delay	Bike Facility Type
7	10	15	3.3	1.9	14	B - Lane

59.8	65

Phase 8 — E/B Ped & Thru

Walk	FDW	Min Green	Yellow	All-Red	Bike Delay	Bike Facility Type
7	12	15	4.2	1.7	19	Sharrow

49.1	55

Cycle: 120

Intersection: **North Ave & West Peachtree**

Wcd N/S (ft)	Wcd E/W (ft)	N/S Speed Limit	E/W Speed Limit	N/S Vehicle Change Period (s)	E/W Vehicle Change Period (s)	N/S Bicycle Minimum Green (s)	E/W Bicycle Minimum Green (s)	N/S BMG Rating	E/W BMG Rating	N/S Bicycle Crossing Time (s)	E/W Bicycle Crossing Time (s)	N/S BCT Assessment	E/W BCT Assessment	Controller BMG Capability	Fixed Time (FT) or Actuated (ACT)
110	90	30	30	6	6	8	7	1	1	10.4	9.0	-1	-1		ACT
										5.3	5.9				

PM — **W Peachtree St** / **North Ave**

Phase 2: W/S Ped & N/B Thru				
Walk	FDW	Yellow	All-Red	Bike Delay
7	21	3.0	2.3	25
	Min Green 15			Bike Facility Type
39.7				B - Lane
45				

Phase 3: E/B LT			
		Yellow	All-Red
	Min Green 5	3.0	2.8
22.2			
28			

Phase 4: W/B Ped & Thur				
Walk	FDW	Yellow	All-Red	Bike Delay
7	21	4.0	1.9	24
	Min Green 9			Bike Facility Type
41.1				-
47				

Cycle: 120

Phase 6: E/S Ped & N/B Thru				
Walk	FDW	Yellow	All-Red	
7	23	3.0	2.3	
	Min Green 15			Bike Facility Type
39.7				B - Lane
45				

Phase 8: E/B Ped & Thru				
Walk	FDW	Yellow	All-Red	Bike Delay
7	23	4.0	1.9	10
	Min Green 9			Bike Facility Type
69.1				-
75				

Cycle: 120

Intersection: **North Ave & West Peachtree**

Wcd N/S (ft)	Wcd E/W (ft)	N/S Speed Limit	E/W Speed Limit	N/S Vehicle Change Period (s)	E/W Vehicle Change Period (s)	N/S Bicycle Minimum Green (s)	E/W Bicycle Minimum Green (s)	N/S BMG Rating	E/W BMG Rating	N/S Bicycle Crossing Time (s)	E/W Bicycle Crossing Time (s)	N/S BCT Assessment	E/W BCT Assessment	Controller BMG Capability	Fixed Time (FT) or Actuated (ACT)
110	90	30	30	6	6	8	7	1	1	10.4	9.0	-1	-1		ACT
										5.3	5.9				

PM — **W Peachtree St** / **North Ave**

Phase 2: W/S Ped & N/B Thru				
Walk	FDW	Yellow	All-Red	Bike Delay
7	21	3.0	2.3	25
	Min Green 15			Bike Facility Type
39.7				B - Lane
45				

Phase 3: E/B LT			
		Yellow	All-Red
	Min Green 5	3.0	2.8
22.2			
28			

Phase 4: W/B Ped & Thur				
Walk	FDW	Yellow	All-Red	Bike Delay
7	21	4.0	1.9	24
	Min Green 9			Bike Facility Type
41.1				Sharrow
47				

Cycle: 120

Phase 6: E/S Ped & N/B Thru				
Walk	FDW	Yellow	All-Red	
7	23	3.0	2.3	
	Min Green 15			Bike Facility Type
39.7				B - Lane
45				

Phase 8: E/B Ped & Thru				
Walk	FDW	Yellow	All-Red	Bike Delay
7	23	4.0	1.9	10
	Min Green 9			Bike Facility Type
69.1				Sharrow
75				

Cycle: 120

Intersection: **10th Street & West Peachtree**

Wcd N/S (ft)	Wcd E/W (ft)	N/S Speed Limit	E/W Speed Limit	N/S Vehicle Change Period (s)	E/W Vehicle Change Period (s)	N/S Bicycle Minimum Green (s)	E/W Bicycle Minimum Green (s)	N/S BMG Rating	E/W BMG Rating	N/S Bicycle Crossing Time (s)	E/W Bicycle Crossing Time (s)	N/S BCT Assessment	E/W BCT Assessment	Controller BMG Capability	Fixed Time (FT) or Actuated (ACT)
126	104	30	30	7	6	9	7	1	1	11.4	10.0	-1	-1		Fixed
										6.3	6.1				

PM — **W Peachtree** — **10th St**

W/S Ped & N/B Thru

Walk	FDW	Yellow	All-Red
7	21	3.3	3.0
	Min Green 15		
29.7			
36			

Bike Delay 46; Bike Facility Type B - Lane; Cycle 150

E/B LT

		Yellow	All-Red
	Min Green 5	3.2	2.5
54.3			
60			

W/B Ped & Thur

Walk	FDW	Yellow	All-Red
7	21	3.2	2.9
	Min Green 9		
47.9			
54			

Bike Delay 33; Bike Facility Type Sharrow

E/S Ped & N/B Thru

Walk	FDW	Yellow	All-Red
7	23	3.3	3.0
	Min Green 15		
29.7			
36			

Bike Facility Type B - Lane; Cycle 150

E/B Ped & Thru

Walk	FDW	Yellow	All-Red
7	23	3.2	2.9
	Min Green 9		
107.9			
114			

Bike Delay 5; Bike Facility Type Sharrow

Intersection: **Peachtree Place & West Peachtree**

Wcd N/S (ft)	Wcd E/W (ft)	N/S Speed Limit	E/W Speed Limit	N/S Vehicle Change Period (s)	E/W Vehicle Change Period (s)	N/S Bicycle Minimum Green (s)	E/W Bicycle Minimum Green (s)	N/S BMG Rating	E/W BMG Rating	N/S Bicycle Crossing Time (s)	E/W Bicycle Crossing Time (s)	N/S BCT Assessment	E/W BCT Assessment	Controller BMG Capability	Fixed Time (FT) or Actuated (ACT)
70	80	30	25	5	6	6	6	1	1	7.6	8.3	-1	-1		ACT

PM — **W Peachtree St** — **Peachtree Place**

Phase 2 — W/S Ped & N/B Thru

Walk	FDW	Yellow	All-Red
7	21	3.1	1.8
	Min Green 15		
58.1			
63			

Bike Delay 15; Bike Facility Type B - Lane; Cycle 120

Phase 4

Walk	FDW	Yellow	All-Red
7	21	3.0	2.9
	Min Green 15		
51.1			
57			

Bike Delay 19; Bike Facility Type Sharrow

Phase 6 — E/S Ped & N/B Thru

Walk	FDW	Yellow	All-Red
7	23	3.1	1.8
	Min Green 15		
58.1			
63			

Bike Facility Type B - Lane; Cycle 120

Phase 8 — E/B Ped & Thru

Walk	FDW	Yellow	All-Red
7	23	3.0	2.9
	Min Green 15		
51.1			
57			

Bike Delay 19; Bike Facility Type Sharrow

Intersection: **8th St & West Peachtree**

Wcd N/S (ft)	Wcd E/W (ft)	N/S Speed Limit	E/W Speed Limit	N/S Vehicle Change Period (s)	E/W Vehicle Change Period (s)	N/S Bicycle Minimum Green (s)	E/W Bicycle Minimum Green (s)	N/S BMG Rating	E/W BMG Rating	N/S Bicycle Crossing Time (s)	E/W Bicycle Crossing Time (s)	N/S BCT Assessment	E/W BCT Assessment	Controller BMG Capability	Fixed Time (FT) or Actuated (ACT)
40	60	30	25	5	5	4	5	1	1	5.6	7.0	-1	-1		Fixed
										5.0	5.6				

PM — **W Peachtree St** / **8th St**

Phase 2 — W/S Ped & N/B Thru

Walk	FDW	Min Green	Yellow	All-Red	Bike Delay	Bike Facility Type
7	21	15	3.1	1.8	9	B - Lane

Cycle 120; 70.1; 75

Phase 4

Walk	FDW	Min Green	Yellow	All-Red	Bike Delay	Bike Facility Type
7	21	15	3.0	2.9	26	-

39.1; 45

Phase 6 — E/S Ped & N/B Thru

Walk	FDW	Min Green	Yellow	All-Red	Bike Facility Type
7	23	15	3.1	1.8	B - Lane

Cycle 120; 70.1; 75

Phase 8 — E/B Ped & Thru

Walk	FDW	Min Green	Yellow	All-Red	Bike Delay	Bike Facility Type
7	23	15	3.0	2.9	26	-

39.1; 45

Intersection: **6th St / Biltmore & West Peachtree**

Wcd N/S (ft)	Wcd E/W (ft)	N/S Speed Limit	E/W Speed Limit	N/S Vehicle Change Period (s)	E/W Vehicle Change Period (s)	N/S Bicycle Minimum Green (s)	E/W Bicycle Minimum Green (s)	N/S BMG Rating	E/W BMG Rating	N/S Bicycle Crossing Time (s)	E/W Bicycle Crossing Time (s)	N/S BCT Assessment	E/W BCT Assessment	Controller BMG Capability	Fixed Time (FT) or Actuated (ACT)
60	81	30	25	5	6	5	6	1	1	7.0	8.4	-1	-1		Fixed
										5.2	5.6				

PM — **W Peachtree St** / **6th St / Biltmore**

Phase 2 — W/S Ped & N/B Thru

Walk	FDW	Min Green	Yellow	All-Red	Bike Delay	Bike Facility Type
7	21	15	3.1	1.8	12	B - Lane

Cycle 120; 63.1; 68

Phase 4

Walk	FDW	Min Green	Yellow	All-Red	Bike Delay	Bike Facility Type
7	21	15	3.0	2.9	21	Sharrow

46.1; 52

Phase 6 — E/S Ped & N/B Thru

Walk	FDW	Min Green	Yellow	All-Red	Bike Facility Type
7	23	15	3.1	1.8	B - Lane

Cycle 120; 63.1; 68

Phase 8 — E/B Ped & Thru

Walk	FDW	Min Green	Yellow	All-Red	Bike Delay	Bike Facility Type
7	23	15	3.0	2.9	21	Sharrow

46.1; 52

Wcd N/S (ft)	Wcd E/W (ft)	N/S Speed Limit	E/W Speed Limit	N/S Vehicle Change Period (s)	E/W Vehicle Change Period (s)	N/S Bicycle Minimum Green (s)	E/W Bicycle Minimum Green (s)	N/S BMG Rating	E/W BMG Rating	N/S Bicycle Crossing Time (s)	E/W Bicycle Crossing Time (s)	N/S BCT Assessment	E/W BCT Assessment	Controller BMG Capability	Fixed Time (FT) or Actuated (ACT)
58	71	30	25	5	5	5	6	1	1	6.8	7.7	-1	-1		ACT

W Peachtree St — **5th St**

PM

	Phase 2					Phase 2					Phase 4				
	W/S Ped & N/B Thru				**Bike Delay**	E/W - Bike Lane				**Bike Delay**	E/B Ped & Thru				**Bike Delay**
	Walk	FDW	Yellow	All-Red		Walk	FDW	Yellow	All-Red		Walk	FDW	Yellow	All-Red	
	0	0			**9**	0	0			**51**	7	11			**35**
		Min Green					Min Green					Min Green			
		15	3.1	2.0	Bike Facility Type		1	3.1	2.0			18	3.0	2.6	Bike Facility Type
Cycle	70.9				B - Lane	6.9					26.4				Sharrow
120	76					12					32				

	Phase 6										Phase 8	
	E/S Ped & N/B Thru					E/W - Bike Lane						**Bike Delay**
	Walk	FDW	Yellow	All-Red		Walk	FDW	Yellow	All-Red			
	7	10				7	10					
		Min Green					Min Green					
		15	3.1	2.0	Bike Facility Type		10	3.0	2.6			Bike Facility Type
Cycle	59.9				B - Lane	49.4						Sharrow
120	65					55						

	Phase 2			
	W/S Ped & N/B Thru			
	Walk	FDW	Yellow	All-Red
	0	0		
		Min Green		
		1	3.0	1.0
	7.0			
	11			

Intersection: **3rd St & West Peachtree**

Wcd N/S (ft)	Wcd E/W (ft)	N/S Speed Limit	E/W Speed Limit	N/S Vehicle Change Period (s)	E/W Vehicle Change Period (s)	N/S Bicycle Minimum Green (s)	E/W Bicycle Minimum Green (s)	N/S BMG Rating	E/W BMG Rating	N/S Bicycle Crossing Time (s)	E/W Bicycle Crossing Time (s)	N/S BCT Assessment	E/W BCT Assessment	Controller BMG Capability	Fixed Time (FT) or Actuated (ACT)
81	90	30	25	5	6	7	7	1	1	8.4	9.0	-1	-1		ACT
										4.9	5.9				

W Peachtree St — **3rd St**

PM

	Phase 2						Phase 4				
	W/S Ped & N/B Thru				**Bike Delay**						**Bike Delay**
	Walk	FDW	Yellow	All-Red			Walk	FDW	Yellow	All-Red	
	7	10			**8**		7	12			**28**
		Min Green						Min Green			
		15	3.4	1.5	Bike Facility Type			20	3.2	2.7	Bike Facility Type
Cycle	74.1				B - Lane		35.1				Sharrow
120	79						41				

	Phase 6						Phase 8				
	E/S Ped & N/B Thru						E/B Ped & Thru				**Bike Delay**
	Walk	FDW	Yellow	All-Red			Walk	FDW	Yellow	All-Red	
	7	10					7	12			**28**
		Min Green						Min Green			
		15	3.4	1.8	Bike Facility Type			20	3.2	2.7	Bike Facility Type
Cycle	73.8				B - Lane		35.1				Sharrow
120	79						41				

Intersection: **Ponce De Leon Ave & West Peachtree**

Wcd N/S (ft)	Wcd E/W (ft)	N/S Speed Limit	E/W Speed Limit	N/S Vehicle Change Period (s)	E/W Vehicle Change Period (s)	N/S Bicycle Minimum Green (s)	E/W Bicycle Minimum Green (s)	N/S BMG Rating	E/W BMG Rating	N/S Bicycle Crossing Time (s)	E/W Bicycle Crossing Time (s)	N/S BCT Assessment	E/W BCT Assessment	Controller BMG Capability	Fixed Time (FT) or Actuated (ACT)
79	77	30	25	5	5	6	6	1	1	8.3	8.1	-1	-1		ACT

PM — W Peachtree St / Ponce De Leon Ave

Cycle: 120

Phase	Movement	Walk	FDW	Min Green	Yellow	All-Red	Green	Split	Bike Delay	Bike Facility Type
Phase 2	W/S Ped & N/B Thru	7	10	15	3.3	1.9	59.8	65	14	B - Lane
Phase 4		7	12	15	4.2	1.7	49.1	55	19	Sharrow
Phase 6	E/S Ped & N/B Thru	7	10	15	3.3	1.9	59.8	65	14	B - Lane
Phase 8	E/B Ped & Thru	7	12	15	4.2	1.7	49.1	55	19	Sharrow

Intersection: **10th Street & Juniper**

Wcd N/S (ft)	Wcd E/W (ft)	N/S Speed Limit	E/W Speed Limit	N/S Vehicle Change Period (s)	E/W Vehicle Change Period (s)	N/S Bicycle Minimum Green (s)	E/W Bicycle Minimum Green (s)	N/S BMG Rating	E/W BMG Rating	N/S Bicycle Crossing Time (s)	E/W Bicycle Crossing Time (s)	N/S BCT Assessment	E/W BCT Assessment	Controller BMG Capability	Fixed Time (FT) or Actuated (ACT)
80	65	30	30	5	5	6	5	1	1	8.3	7.3	-1	-1		Fixed
										5.6	5.7				

PM — Juniper / 10th St

Cycle: 120

Phase	Movement	Walk	FDW	Min Green	Yellow	All-Red	Green	Split	Bike Delay	Bike Facility Type
Phase 1										
Phase 2	W/S Ped & N/B Thru	10	21	15	3.0	2.6	44.4	50	22	B - Lane
Phase 3										
Phase 4	W/B Ped & Thur	10	11	12	3.5	2.2	64.3	70	12	Sharrow
Phase 5										
Phase 6	E/S Ped & N/B Thru	10	15	15	3.0	2.6	44.4	50		B - Lane
Phase 7	S/B LT			5	3.0	2.2	20.0	20		
Phase 8	E/B Ped & Thru	10	14	12	3.5	2.2	44.3	50	22	Sharrow

Intersection: **8th St &Juniper**

Wcd N/S (ft)	Wcd E/W (ft)	N/S Speed Limit	E/W Speed Limit	N/S Vehicle Change Period (s)	E/W Vehicle Change Period (s)	N/S Bicycle Minimum Green (s)	E/W Bicycle Minimum Green (s)	N/S BMG Rating	E/W BMG Rating	N/S Bicycle Crossing Time (s)	E/W Bicycle Crossing Time (s)	N/S BCT Assessment	E/W BCT Assessment	Controller BMG Capability	Fixed Time (FT) or Actuated (ACT)
40	65	30	25	5	5	5	5	1	1	5.6	7.3	-1	-1		Fixed
										4.5	5.3				

PM

	Phase 2					Phase 4				
	W/S Ped & N/B Thru				Bike Delay					Bike Delay
	Walk	FDW	Yellow	All-Red	11	Walk	FDW	Yellow	All-Red	23
	7	10	3.0	1.5		7	10	3.0	2.3	
		Min Green			Bike Facility Type		Min Green			Bike Facility Type
		15					9			
Cycle	66.5				B - Lane	43.7				Sharrow
120	71					49				

	Phase 6					Phase 8				
	E/S Ped & N/B Thru					E/B Ped & Thru				Bike Delay
	Walk	FDW	Yellow	All-Red		Walk	FDW	Yellow	All-Red	23
	7	10	3.0	1.5		7	10	3.0	2.3	
		Min Green			Bike Facility Type		Min Green			Bike Facility Type
		15					9			
Cycle	66.5				B - Lane	43.7				Sharrow
120	71					49				

Intersection: **Juniper & 7th St**

Wcd N/S (ft)	Wcd E/W (ft)	N/S Speed Limit	E/W Speed Limit	N/S Vehicle Change Period (s)	E/W Vehicle Change Period (s)	N/S Bicycle Minimum Green (s)	E/W Bicycle Minimum Green (s)	N/S BMG Rating	E/W BMG Rating	N/S Bicycle Crossing Time (s)	E/W Bicycle Crossing Time (s)	N/S BCT Assessment	E/W BCT Assessment	Controller BMG Capability	Fixed Time (FT) or Actuated (ACT)
50	65	30	25	5	5	5	6	1	1	6.3	7.3	-1	-1		ACT
										4.6	5.2				

PM

	Juniper					7th St				
	Phase 2					Phase 4				
	W/S Ped & N/B Thru				Bike Delay					Bike Delay
	Walk	FDW	Yellow	All-Red	12	Walk	FDW	Yellow	All-Red	21
	7	10	3.0	1.6		7	11	3.0	2.2	
		Min Green			Bike Facility Type		Min Green			Bike Facility Type
		15					9			
Cycle	63.4				B - Lane	46.8				-
120	68					52				

	Phase 6		Phase 8	
				Bike Delay
		Bike Facility Type		Bike Facility Type
Cycle		B - Lane		-
0				

Intersection: **Juniper St & 6th St**

Wcd N/S (ft)	Wcd E/W (ft)	N/S Speed Limit	E/W Speed Limit	N/S Vehicle Change Period (s)	E/W Vehicle Change Period (s)	N/S Bicycle Minimum Green (s)	E/W Bicycle Minimum Green (s)	N/S BMG Rating	E/W BMG Rating	N/S Bicycle Crossing Time (s)	E/W Bicycle Crossing Time (s)	N/S BCT Assessment	E/W BCT Assessment	Controller BMG Capability	Fixed Time (FT) or Actuated (ACT)
41	60	30	25	5	5	4	4	1	1	5.7	7.0	-1	-1		ACT
										4.8	6.0				

PM — **Juniper** — **6th St**

Phase 2: W/S Ped & N/B Thru

Walk	FDW	Yellow	All-Red
7	10	3.3	1.5
	Min Green 15		
90.2			
95			

Bike Delay: 3
Bike Facility Type: B - Lane

Cycle: 120

Phase 4

Walk	FDW	Yellow	All-Red
7	10	3.0	3.0
	Min Green 18		
19.0			
25			

Bike Delay: 40
Bike Facility Type: -

Phase 6

Bike Facility Type: B - Lane

Cycle: 0

Phase 8

Bike Delay

Bike Facility Type: -

Intersection: **Juniper St & 5th St**

Wcd N/S (ft)	Wcd E/W (ft)	N/S Speed Limit	E/W Speed Limit	N/S Vehicle Change Period (s)	E/W Vehicle Change Period (s)	N/S Bicycle Minimum Green (s)	E/W Bicycle Minimum Green (s)	N/S BMG Rating	E/W BMG Rating	N/S Bicycle Crossing Time (s)	E/W Bicycle Crossing Time (s)	N/S BCT Assessment	E/W BCT Assessment	Controller BMG Capability	Fixed Time (FT) or Actuated (ACT)
55	55	30	25	5	5	5	5	1	1	6.6	6.6	-1	-1		Actuated
										5.1	4.9				

PM — **Juniper St** — **5th St**

Phase 2: W/S Ped & N/B Thru

Walk	FDW	Yellow	All-Red
7	10	3.5	1.6
	Min Green 15		
65.9			
71			

Bike Delay: 11
Bike Facility Type: B - Lane

Cycle: 120

Phase 4

Walk	FDW	Yellow	All-Red
7	12	3.0	1.9
	Min Green 9		
44.1			
49			

Bike Delay: 23
Bike Facility Type: Sharrow

Phase 6: E/S Ped & N/B Thru

Walk	FDW	Yellow	All-Red
7	10	3.5	1.6
	Min Green 15		
65.9			
71			

Bike Facility Type: B - Lane

Cycle: 120

Phase 8: E/B Ped & Thru

Walk	FDW	Yellow	All-Red
7	14	3.0	1.9
	Min Green 9		
44.1			
49			

Bike Delay: 23
Bike Facility Type: Sharrow

Intersection: **3rd St & Juniper**

Wcd N/S (ft)	Wcd E/W (ft)	N/S Speed Limit	E/W Speed Limit	N/S Vehicle Change Period (s)	E/W Vehicle Change Period (s)	N/S Bicycle Minimum Green (s)	E/W Bicycle Minimum Green (s)	N/S BMG Rating	E/W BMG Rating	N/S Bicycle Crossing Time (s)	E/W Bicycle Crossing Time (s)	N/S BCT Assessment	E/W BCT Assessment	Controller BMG Capability	Fixed Time (FT) or Actuated (ACT)
24	65	30	25	4	5	3	5	1	1	4.5	7.3	-1	-1		ACT
										4.6	5.8				

PM — **Juniper** / **3rd St**

Cycle: 120

Phase 2 — W/S Ped & N/B Thru

Walk	FDW	Yellow	All-Red
7	12	3.1	1.5
	Min Green 15		
73.4			
78			

Bike Delay: 8
Bike Facility Type: B - Lane

Phase 4 — E/B Ped & Thru

Walk	FDW	Yellow	All-Red
7	12	3.6	2.2
	Min Green 12		
36.2			
42			

Bike Delay: 27
Bike Facility Type: Sharrow

Cycle: 120

Phase 6 — E/S Ped & N/B Thru

Walk	FDW	Yellow	All-Red
7	12	3.1	1.5
	Min Green 15		
73.4			
78			

Bike Facility Type: B - Lane

Phase 8 — E/B Ped & Thru

Walk	FDW	Yellow	All-Red
7	12	3.6	2.2
	Min Green 12		
36.2			
42			

Bike Delay: 27
Bike Facility Type: Sharrow

Juniper St & Ponce De Leon Ave

Wcd E/W (ft)	N/S Speed Limit	E/W Speed Limit	N/S Vehicle Change Period (s)	E/W Vehicle Change Period (s)	N/S Bicycle Minimum Green (s)	E/W Bicycle Minimum Green (s)	N/S BMG Rating	E/W BMG Rating	N/S Bicycle Crossing Time (s)	E/W Bicycle Crossing Time (s)	N/S BCT Assessment	E/W BCT Assessment	Controller BMG Capability	Fixed Time (FT) or Actuated (ACT)
75	30	25	6	5	12	11	1	1	9.0	8.0	-1	-1		ACT
									6.2	5.3				

Juniper / **Ponce De Leon**

Phase 1

Phase 2 — W/S Ped & S/B Thru

Walk	FDW	Yellow	All-Red
7	19	3.4	2.8
	Min Green 15		
71.8			
78			

Bike Delay: 9
Bike Facility Type: B - Lane

Phase 3

Phase 4 — W/B Ped & Thur

Walk	FDW	Yellow	All-Red
7	12	3.0	2.3
	Min Green 18		
36.7			
42			

Bike Delay: 27
Bike Facility Type: Sharrow

Phase 5 — S/B LT

		Yellow	All-Red
	Min Green 5	3.0	3.2
20.0			
46			

Phase 6 — W/S Ped & S/B Thru

Walk	FDW	Yellow	All-Red
7	15	3.4	2.8
	Min Green 15		
25.8			
32			

Bike Facility Type: B - Lane

Phase 7

Phase 8 — E/B Ped & Thru

Walk	FDW	Yellow	All-Red
7	15	3.0	2.3
	Min Green 18		
36.7			
42			

Bike Delay: 27
Bike Facility Type: Sharrow

Intersection: **Juniper St & North Ave**

Wcd N/S (ft)	Wcd E/W (ft)	N/S Speed Limit	E/W Speed Limit	N/S Vehicle Change Period (s)	E/W Vehicle Change Period (s)	N/S Bicycle Minimum Green (s)	E/W Bicycle Minimum Green (s)	N/S BMG Rating	E/W BMG Rating	N/S Bicycle Crossing Time (s)	E/W Bicycle Crossing Time (s)	N/S BCT Assessment	E/W BCT Assessment	Controller BMG Capability	Fixed Time (FT) or Actuated (ACT)
94	84	30	30	6	6	13	12	1	1	9.3	8.6	-1	-1		ACT
										6.1	6.4				

PM — **Juniper** / **North Ave**

Phase	Movement	Walk	FDW	Min Green	Green	Yellow	All-Red	Split
Phase 1								
Phase 2	W/S Ped & N/B Thru	7	10	15	68.9	3.9	2.2	75
Phase 3								
Phase 4	W/B Ped & Thur	7	12	21	38.6	3.7	2.7	45
Phase 5	S/B LT			5	20.0	3.0	2.2	25
Phase 6	E/S Ped & N/B Thru	7	12	15	43.9	3.9	2.2	50
Phase 7								
Phase 8	E/B Ped & Thru	7	17	21	38.6	3.7	2.7	45

Cycle: 120 (Phases 1–4); Cycle: 120 (Phases 5–8)

Bike Delay: 10

Bike Facility Type: B - Lane (Phases 2/3)

Bike Facility Type: B - Lane (Phases 6/7)

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